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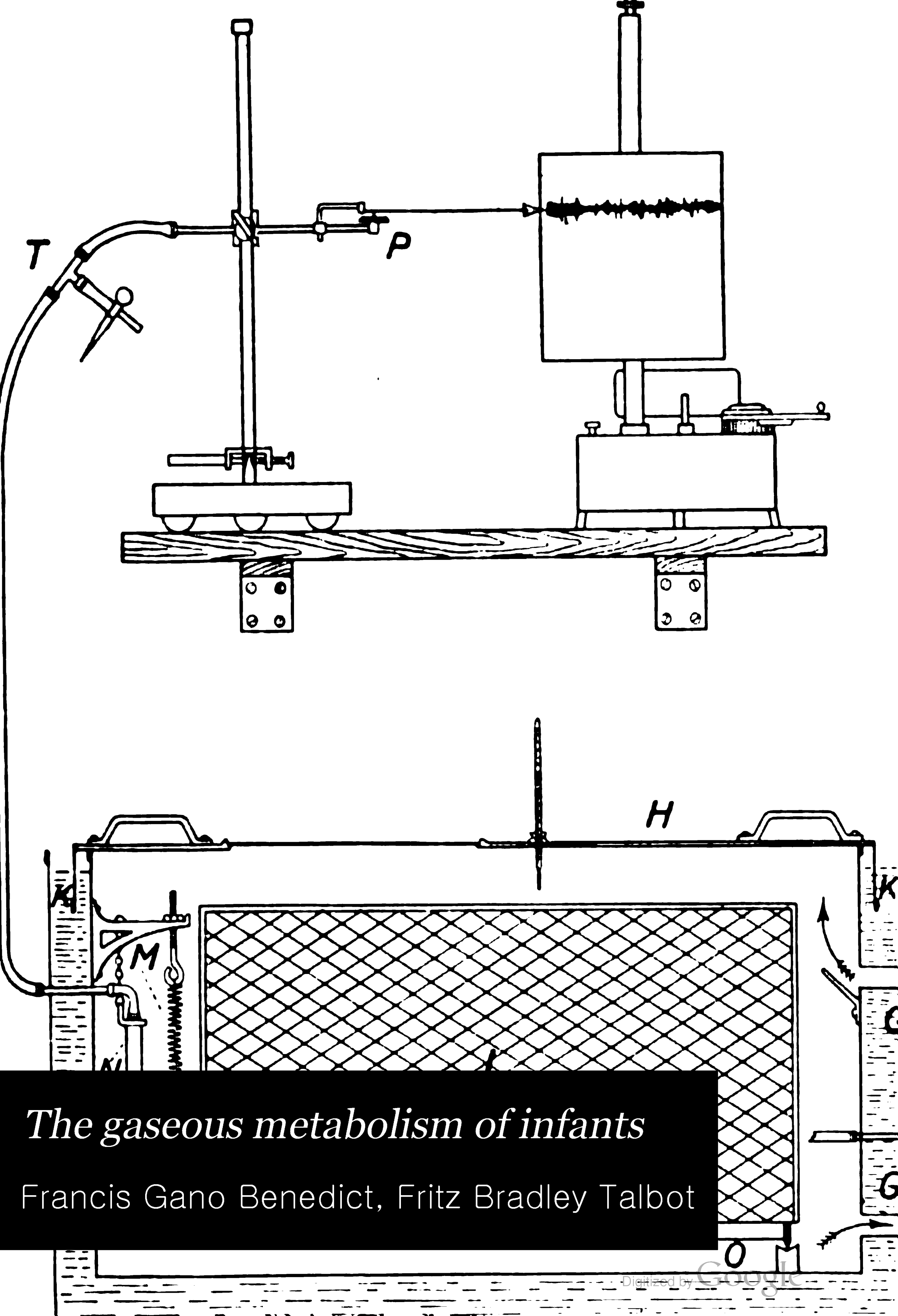

The gaseous metabolism of infants

Francis Gano Benedict, Fritz Bradley Talbot

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THE GASEOUS METABOLISM OF INFANTS

WITH SPECIAL REFERENCE TO ITS RELATION TO PULSE-RATE AND MUSCULAR ACTIVITY

BY

FRANCIS G. BENEDICT AND FRITZ B. TALBOT

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PREFACE.

These observations were made in the Children's Department of the Massachusetts General Hospital with an apparatus belonging to the Nutrition Laboratory. The experimental technique was exclusively under the charge of Miss Alice Johnson, of the Nutrition Laboratory staff. For her extraordinarily painstaking skill and fidelity we are under great obligations.

Of the numerous co-workers in this research we wish especially to mention Doctors S. Morgulis and J. L. Gamble, and of the various house officers and nurses, Dr. R. E. Eustis, Dr. Clifford B. Sweet, and the Misses Trainer, Sullivan, and Richardson.

The obtaining of subjects for observation was much facilitated by the kindness and assistance of Dr. F. A. Washburn, the superintendent of the Massachusetts General Hospital, and various members of his staff.

Our thanks are due to Dr. J. H. Wright of the Pathological Department, who placed an excellent room in his laboratory at our disposal.

We are particularly indebted to Dr. Hans Murschhauser of Düsseldorf, Research Associate of the Carnegie Institution of Washington, attached to this laboratory, for his reading of the entire manuscript and for numerous helpful suggestions.

The labor of preparing much of the material in this report has fallen upon Miss A. N. Darling and Mr. W. H. Leslie, whose assistance we gratefully acknowledge.

NUTRITION LABORATORY OF THE
CARNEGIE INSTITUTION OF WASHINGTON,
Boston, Massachusetts, February 7, 1914.

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THE GASEOUS METABOLISM OF INFANTS

WITH SPECIAL REFERENCE TO ITS RELATION TO PULSE-RATE AND MUSCULAR ACTIVITY

BY

FRANCIS G. BENEDICT AND FRITZ B. TALBOT

PART I.

INTRODUCTION.

Observations on the metabolism of infants have for the most part been confined to records of food intake, changes in body-weight, and analyses of urine and feces. Studies of the gross metabolism of the body, necessitating either direct calorimetric observations or measurements of the gaseous exchange, demand elaborate apparatus and unusual technique and hence they have been precluded in most clinics and laboratories. Before entering into a discussion of our researches in this field, it is desirable to cite briefly the evidence on the gaseous exchange of infants thus far published.

The earliest record that we have been able to find of the measurement of the gaseous metabolism of an infant is that reported by J. Forster, of Munich, in 1877.[1] In an effort to explain the well-known fact that children consume a larger amount of food in proportion to their body-weight than do adults, this investigator made determinations of the carbon-dioxide excretion in 14 experiments on children varying in age from 14 days to 9 years. His results all showed that 10 or 12 grams of carbon dioxide were given off per hour for every 10 kilograms of body-weight. With adults on the same basis, the carbon dioxide given off under conditions of rest and approximate hunger was 4 to 5 grams per hour; with an average diet, 5 to 6 grams; and with food and work, 7 grams. The author points out that the youthful organism, even in the condition of hunger, produces per unit of weight at least twice the amount of carbon dioxide which is produced by the adult body. The fact is also recognized that the infant can develop a considerable amount of work, as will be seen by the following quotation:

> "Bedenkt man noch die relativ grossen Arbeitsleistungen, welche die meist lebhaften kindlichen Körper ausführen, so ergibt sich, dass eine relative Mehrzufuhr von Speisen für den kindlichen Organismus eine durch innere Verhältnisse bedingte Nothwendigkeit ist."

The experiments were made with the large Pettenkofer-Voit respiration chamber in Munich, but the protocols were never published, and aside from the statement that the children were at rest, no further details are given as to the muscular activity or the pulse-rate.

In 1885 Richet,[2] in describing his calorimeter, states that he has two chambers, one of which, having a capacity of about 1,500 liters of air, is used for experiments with infants. He cites an experiment with an infant of 9 kilograms, who was in the chamber for 1 hour and 10 minutes, and gives protocols for another experiment, 1 hour in length, presumably with the same infant. In summing up his averages he refers to numerous experiments on infants weighing from 6 to 9 kilograms and includes observations made with environmental temperatures ranging from 18° C. to 25° C. He concludes that the infant produces on the average 4 calories per kilogram of body-weight per hour. Richet discusses especially the relationship between the body-surface and the heat-production.

---

[1] Forster, Amtl. Ber. d. 50. Versammlung deutsch. Naturforscher u. Aerste in Munchen, Munich, 1877, p. 355.

[2] Richet, Archives de Physiol. norm. et path., 1885, **15**, 3d ser., p. 237.

Two years later, Langlois[1] conducted experiments on children with Richet's calorimeter, in which only the heat-production was measured. From 17 controlled experiments, all with infants weighing about 7 kilograms, Langlois concludes that the heat-production is increased as the environmental temperature is lowered. As a result of a study on the influence of the time of day upon the heat-production, he also concludes that there are two maximum values at approximately 11 a. m. and 3 p. m., corresponding to the values for the absorption of oxygen found by Fredericq.[2]

Table 1.—*Relationship between heat-production and body-weight of infants* (Langlois).

Body-weight.		Heat-production per kilogram of body-weight.
	kilos.	*cals.*
Two children at	1.8	6.40
Child of	2.5	4.80
Children from	3.0 to 4.0	4.20
Children from	7.0 to 8.0	4.12
Children from	9.0 to 10.0	3.93

Table 2.—*Relationship between heat-production and body-surface of infants* (Langlois).

Body-weight.	Body-surface.	Heat-production.		
		Per kilogram of body-weight.	Per unit of surface.	Per sq.meter of body-surface.[2]
kilos.		*cals.*	*cals.*	*cals.*
10	9.142[1]	3.920	17	1,690
9	2.106	3.900	16	1,620
7	1.778	4.120	16	1,580
6	1.638	4.200	15	1,500
4	1.135	4.300	15	1,370
2	0.780	6.000	15	1,510

[1] This figure is quoted from Langlois and as his discussion of body-surface is very confusing, it is impossible to make a correction which is obviously much needed.

[2] As calculated by Camerer, using Meeh's formula (Camerer, Der Stoffwechsels des Kindes, Tübingen, 1896, p. 109).

Langlois's discussion of the relationships between the heat-production and the body-weight and the heat-production and the body-surface is of special interest in connection with our research. As will be seen from his figures given in table 1, the smaller the child the larger was the heat-production per kilogram of body-weight. The author points out, however, that if the heat-production and body-surface are compared, as is done in table 2, the uniformity is remarkable. He gives a very unsatisfactory explanation of his unit of surface, but brings out the fundamental idea that the heat per unit of body-surface is essentially the same for an infant as for an adult weighing 65 kilograms, namely, 14 to 17 calories. No information is given regarding the muscular activity, the age, or the pulse-rate of these infants.

---

[1] Langlois, Centralbl. f. Physiol., 1887, **1**, p. 237. [2] Fredericq, Arch. de Biol., 1882, **3**, p. 731.

In another paper, Langlois[1] refers to Richet's observations on normal children weighing from 7 to 10 kilograms with a heat-production of approximately 4,000 calories per kilogram per hour, and reports his own results with sick infants in which he finds a direct relationship between the body-temperature and heat-production. Infants having temperatures below 37.5° C., which he takes as normal, had a heat-production less than 4 calories per kilogram of body-weight per hour, while those with temperatures above 37.5° C. had a higher heat-production; thus, with a body-temperature of 35.5° C., the heat-production was equal to 2,900 calories, while with a body-temperature of 40.5° C., it was equal to 4,600 calories.

Langlois's calorimeter was subsequently used by Variot and Saint-Albin[2] in studying the calorimetry of atrophic infants. The tests of this calorimeter published by Saint-Albin[3] show a possible error of plus or minus 10 per cent, thus indicating that the apparatus can hardly be considered an instrument of precision. As Saint-Albin himself points out, his check tests differ considerably from those of Langlois.

Variot and Saint-Albin studied a large number of atrophic infants; their conclusions, reported by Saint-Albin, are especially interesting in connection with this report of our researches, as they show that (using their terminology) out of 33 atrophic infants, there were 11 "hyperrayonnants," 16 "hyporayonnants," and 6 "rayonnants normalement."[4]

Of the numerous forms of calorimeters reported to the French scientific societies by d'Arsonval, one[5] was employed by Bonniot[6] in 1898 for a study of the heat-production of infants with temperature disturbances, but he found no regular relationship between heat radiation and rectal temperature. A detailed presentation of Bonniot's results may be found in his thesis for 1900.[7]

---

[1] Langlois, Compt. rend., 1887, 104, p. 860.

[2] Variot and Saint-Albin, Bull. de la Soc. de Pediatre. 1903, **5**, pp. 246 and 307. See, also, an extensive discussion of these researches in the thesis by Saint-Albin, Etude sur la calorimétrie des infants atrophiques, Paris, 1904, No. 295.

[3] Saint-Albin, loc. cit., p. 25. [4] *Ibid.*, p. 39.

[5] See note on this particular calorimeter by d'Arsonval, Mem. de la Soc. de Biol., 1898, p. 248.

[6] Bonniot, Mem. de la Soc. de Biol., 1898, p. 249. For a critique of the Richet and d'Arsonval calorimeters, see Bonniot, Calorimetrie infantile. Etat de la question. Clinique Infantile, 1906, **4**, p. 289.

[7] Bonniot, De l'hyperthermie dans la fiévre; essai de calorimétrie clinique, Paris, 1900, No. 419.

The most recent contribution from French laboratories on direct calorimetry with which we are familiar is that of Variot and Lavialle[1] in 1912. In this interesting communication, in which the fundamental principles of infant calorimetry are well considered, the authors state that they used the modified form of the d'Arsonval calorimeter which was calibrated by electrical resistance. The gaseous metabolism was not studied and no statement was made as to the muscular activity of the infants. The authors conclude that the heat-output of infants increases in proportion as the weight decreases and lay great emphasis upon the effect of clothing upon radiation. They likewise believe that the supply of adipose tissue may materially modify the radiation.

Mensi[2] of Turin, without stating the apparatus employed or even the fundamental principle, reports a series of observations on 5 new-born infants varying in age from 6 hours and 5 minutes to 7 days, 17 hours, and 54 minutes. In these experiments the oxygen consumption was determined as well as the carbon-dioxide production. The results are given in table 3. The statement is made that the infants were quiet in each case, but no pulse records are given.

TABLE 3.—*Summary of experiments on respiratory exchange of new-born infants* (Mensi).

Age.	Sex.	Body-weight.	Length of experiment.	Oxygen consumed.			Carbon dioxide produced.				Respiratory quotient.
				Total.	Per minute.	Per kilogram per minute.	Total.	Per minute.	Per kilogram per minute.		
d. h. m.		*kilos.*	*mins.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*mg.*	
6 5	M.	2.70	173	5,707	32.9	12.18	4,174	24.1	8.92	16.08	0.73
1 2 47	M.	3.—	173	6,470	37.4	12.46	3,844	22.2	7.40	13.34	0.593
3 1 55	M.	2.92	159	6,216	39.09	13.38	3,442	21.64	7.41	13.36	0.55
3 7 22	F.	2.47	171	5,463	31.9	12.91	3,586	20.9	8.46	15.25	0.655
7 17 54	M.	2.32	149	4,997	33.5	14.43	2,979	19.9	8.57	15.45	0.59

A very interesting series of experiments on infants was carried out by Scherer, in the institute of Professor Mareš in Prague,[3] with an apparatus on the Regnault-Reiset principle, the oxygen being supplied from a bomb. The author states that the infants found themselves in "complete physiological conditions" inside the chamber. In this series, 55 experiments were made in the spring and summer and 30 experiments in the winter, each one being about 2 hours long. No information is given regarding the activity of the infants or the pulse-rate. The fact that the average respiratory quotients were considerably below 0.6 points strongly to an error in the method. The author concludes that the intensity of the respiratory exchange is dependent upon the body-weight and is inversely proportional to it.

---

[1] Variot and Lavialle, Bulletins and Mémoires Soc. Med. des Hôpitaux de Paris, 1912, 3d ser., **33**, p. 410. See also Clinique Infantile, 1912, **10**. p. 229, and Report of the Congrès National des Gouttes de Lait ténu à Fécamp les 26, 27, et 28 Mai, 1912, p. 79, for abstracts of this work.

[2] Mensi, Giorn. d. R. Accad. di Med. di Torino, 1894, **57**, p. 301.

[3] Scherer, Jahrb. f. Kinderheilk., 1896, N. F., **43**, p. 471.

Two years later the classic monograph of Rubner and Heubner[1] appeared. In discussing the earlier observations of Forster, they add the significant fact that Forster's experimental periods were but one hour long. As their own work was done with the Pettenkofer chamber, they criticize adversely the closed-circuit apparatus used by Scherer and particularly the fundamental principle of using experiments with short periods, their paper setting forth fully the arguments in favor of the long experimental period and the Pettenkofer type of respiration chamber as compared with the short period and the Regnault-Reiset chamber. The Pettenkofer chamber, which had previously been described,[2] was slightly modified for the studies of Rubner and Heubner, a small chamber being used.

The fundamental question studied by Rubner and Heubner was the nourishment of an infant from a practical standpoint; and they were accordingly more interested in the average daily requirement of an infant for nourishment than in the physiological fact of the minimum requirement for comparison with other individuals. The subject—a "normal" infant—was 9 weeks old at the time of the observation and weighed 5,220 grams. The infant was placed in the respiration chamber and removed and fed from 6 to 8 times each day, the time thus lost being carefully recorded. Ocular observations of the muscular activity were made and a general impression for each day recorded. Much of the time, the infant was awake but not crying. On the basis of 24 hours the authors found a difference of 22 per cent between minimum and maximum carbon-dioxide production. They state that this difference is due to the unequal activity of the infant, emphasizing especially the fact that disturbance of sleep during the night influences the total daily average of the metabolism.

Using Meeh's formula[3] ($S=11.9\sqrt[3]{W}$) and a body-weight of 5.1 kg. they compute the body-surface to be equal to 3,500 sq. cm. and find a carbon-dioxide production of 13.5 grams per square meter of body-surface per hour. Comparing this value with those found with adults, they state that the infant excreted less carbon dioxide per square meter of body-surface than did the adults and explain this by the fact that the infant was asleep a part of the time while the determinations with adults were made only when the subjects were awake. Having pointed out that their results contradict those of Sondén and Tigerstedt,[4] which showed an increased production of carbon dioxide in youth, they emphasize the fact that the carbon dioxide is essentially proportional to the body-surface with human individuals of any size.

Shortly after the publication of their investigations with a normal, breast-fed infant, Rubner and Heubner[5] reported a comparative study with a normal and an atrophic infant, neither being breast-fed. This study was carried out on the same plan as that used for the former experiment. The "normal" infant weighed 7.57 kilograms, was 7½ months old, and appeared to be in good health. She was fed on milk and milk sugar and throughout the observation was said to be in general "*recht ruhig.*" The results were compared with those obtained with the breast-fed infant in the previous experiment, the hourly excretion of carbon dioxide per square meter of body-surface being but 13.5 grams for the breast-fed infant, which weighed but 5 kilograms, and 17.3 grams for the artificially fed infant, which weighed 7.6 kilograms.

---

[1] Rubner and Heubner, Zeitschr. f. Biol., 1898, **36**, p. 1.
[2] Wolpert, Archiv f. Hyg., 1896, **26**, p. 32.
[3] Meeh, Zeitschr. f. Biol., 1879, **15**, p. 425.
[4] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 1.
[5] Rubner and Heubner, Zeitschr. f. Biol., 1899, **38**, p. 315.

TABLE 4.—*Results of experiments with a normal infant and an atrophic infant.* (Rubner and Heubner).

Description of subject.	Food.	Period.	Calories per square meter of body-surface.
Normal.....	Breast-fed.	....	1,006
	Cow milk.	I	1,143
	"	II	1,233
	"	III	1,378
Atrophic....	"	I	1,090
	"	II	1,171
	Meal.	....	1,036

The second portion of the paper deals with the metabolism of the atrophic infant, artificially fed with cow's milk and "*Kindermehl.*" Their results are given in table 4. The authors conclude that there was nothing abnormal in the metabolism of the atrophic infant.

TABLE 5.—*Results of experiments on the respiratory exchange of atrophic infants* (Poppi).

Name.	Date.	Duration.	Body-weight.	Age.	Carbon dioxide produced.			Oxygen produced.			Respiratory quotient.
					Total.	Per 24 hours.	Per kg. per minute.	Total.	Per 24 hours.	Per kg. per minute.	
	1899.	*h. m.*	*kilos.*	*mos.*	*c.c.*	*liters.*	*c.c.*	*c.c.*	*liters.*	*c.c.*	
P.L.	July 11	1 15	3.425	9	2,166	40.62	8.237	2,084	40.02	8.114	1.015
N.B.	20	2 0	3.865	10	3,900	46.80	8.409	3,820	45.84	8.236	1.021
C.F.	Nov. 10	2 0	5.500	16	4,125	49.50	6.25	4,621	55.452	7.002	0.893
A.F.	12	2 0	3.465	7	3,177	38.13	7.642	3,027	36.324	7.280	1.050
M.G.	15	2 0	5.450	12	4,071	48.852	6.225	4,186	50.232	6.40	0.973
F.G.	Dec. 8	2 0	2.780	3½	2,667	32.004	8.07	2,642	31.704	7.92	1.019
	1900.										
E.N.	Feb. 3	2 0	3.940	4	3,009	36.108	6.364	3,223	38.676	6.818	0.933

The first extensive study exclusively with atrophic infants was made by Poppi.[1] A respiration apparatus of the closed-circuit type was probably used, as both the carbon-dioxide production and the oxygen consumption were measured, though little is said of the method. An abstract of the results obtained with 7 infants is given in table 5.

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[1] Poppi, Il ricambio materiale e il ricambio respiratorio nell'atrofia infantile, Bologna, 1900.

The respiratory quotients all seem unusually high, and this fact throws doubt upon the accuracy of the research. It is probable, however, that the carbon-dioxide determinations are well within the limits of accuracy, as is usual with methods of this type. From the protocols of one of Poppi's studies it appears that the experiments were each 2 hours long, but no estimations are given regarding the muscular activity or the pulse-rate.

In 1904 Rubner and Heubner[1] reported another series of experiments covering a period of 5 days. The subject was a breast-fed infant, 5½ months old and weighing 9.7 kilograms. Notwithstanding the apparently large changes in the activity from day to day, the investigators found that the carbon-dioxide output on the last 4 days was fairly constant—a fact which puzzled the authors, who suggest a compensatory influence in the life of the infant. They compare the results found in this observation with those secured with other infants in the previous work done by them, and find an increase in the carbon-dioxide output of 21 per cent over the results obtained with the breast-fed infant previously studied. (See table 6.) This increase they explain by saying that it is due to the greater activity of the infant in the last experiment.

TABLE 6.—*Metabolism of infants compared* (Rubner and Heubner).

Subjects and diet.	Body-weight.	Calories per square meter of body-surface per day.
	kilos.	
Atrophic child (cow milk)	3	1,090
Breast child	5	1,006
Child (cow milk)	8	1,143
Child (breast, of this experiment)	10	1,219

In 1908 a report appeared of the first in a remarkable series of experiments carried out by Schlossmann and Murschhauser in Düsseldorf.[2] The protocols of this experiment were given in connection with a description of the testing of the modified Regnault-Reiset apparatus constructed by Zuntz and Oppenheimer. The authors, Schlossmann, Oppenheimer, and Murschhauser, emphasize the importance of observations when the infant is asleep; they accordingly preferred to make their observations the first half of the night, feeding the infant with a large amount of breast milk in the early evening. The measurements of the metabolism of the infant during this experiment are given in table 7. During the experimental period the infant weighed 5.79 kilograms, the calculated body-surface being 0.384 square meter (using Meeh's formula given on page 15).

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[1] Rubner and Heubner, Zeitschr. f. exp. Path. u. Therapie, 1904–05, **1**, p. 1.

[2] Schlossmann, Oppenheimer, and Murschhauser, Biochem. Zeitschr., 1908, **14**, p. 385.

The same infant was subsequently studied by Schlossmann and Murschhauser[1] at the ages of 144 days, 284 days, and 380 days. They found no difference in the metabolism per square meter of body-surface and conclude that Rubner's law is correct and that the metabolic processes are proportional to the body-surface.

TABLE 7.—*Metabolism of an infant* (Schlossmann and Murschhauser).
(Per square meter of body-surface per hour.)

	Oxygen consumption.	Carbon-dioxide production.
	gms.	*gms.*
Average during 8 hours sleep...	11.0	13.78
Shortly after feeding..........	11.88	15.52
Three hours after feeding......	10.42	12.68
Waking and sleeping..........	12.85	15.75

The report of the first extensive research made by Schlossmann and Murschhauser appeared in 1910.[2] This is of special interest, inasmuch as the authors recognize at the outset the importance of muscular repose and of determining the basal metabolism. Many valuable suggestions as to the selection of infants for such study are incorporated in the report. Observations were made on 3 female infants; the results of these are given in table 8. The authors conclude that the carbon-dioxide production and the oxygen consumption depend upon the body-surface, being wholly independent of the age of the subject, and draw the general conclusion that the infant produces per square meter of body-surface about 12 grams of carbon dioxide and consumes about 11 grams of oxygen per hour.

TABLE 8.—*Results of fasting experiments with infants during approximately absolute rest* (Schlossmann and Murschhauser).

Subject.	Age.	Weight.	Body-surface.	Carbon-dioxide per square meter per hour.	Oxygen per square meter per hour.	Respiratory quotient.
	days	*kilos.*	*sq. m.*	*grams.*	*grams.*	
S........	174	5.010	0.3505	12.27	10.56	0.847
	180	5.115	.3553	12.22	10.81	.824
P........	149	4.220	.3124	12.35	10.52	.856
	169	4.430	.3228	12.64	11.08	.832
L........	87	4.980	.3491	12.33	12.22	.730
	93	5.040	.3519	11.48	10.93	.760

Recognizing the possibility that the environmental temperature may have an effect upon the metabolism of the infant, Schlossmann and Murschhauser discussed this point in 1911,[3] giving the results of experiments with an infant in which the temperature of the surrounding atmosphere varied from 16.3° C. to 23.4° C. Another infant was studied with temperatures varying from 16.9° C. to 23.4° C. The results of this second experiment substantiated those obtained with the first infant, and the authors feel justified in concluding that the slight temperature changes found in experiments with an apparatus of the Regnault-Reiset type are entirely without influence upon the metabolism of the individuals studied.

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[1] Schlossmann and Murschhauser, Biochem. Zeitschr., 1909, 18, p. 499.
[2] *Ibid.*, 1910, 26, p. 14.
[3] *Ibid.*, 1911, 37, p. 1.

The same investigators,[1] with a keen appreciation of the influence of muscular activity upon metabolism, compared the results of observations with an infant who cried continuously for an hour with those obtained when the infant was approximately quiet. They estimated that the crying increased the carbon-dioxide production 59.4 per cent and the oxygen consumption 44 per cent.

In still another paper Schlossmann[2] discusses the general principles involved in the measurement of the respiratory exchange of infants and emphasizes the necessity of muscular repose and the absence of food, and the importance of measuring the basal metabolism. He again asserts that the heat per square meter of body-surface is constant and maintains that this is a proof that the metabolism of young individuals is not variable. In this paper, also, he discusses the amount of work the infant does, basing the discussion upon results obtained in his experiments with crying infants. In many of his experiments Schlossmann measured the skin-temperature of the infant by electrical methods and found that there was no increase in the temperature.

In a paper discussing his earlier experiments on infants of varying ages and particularly those with an atrophic infant, Schlossmann opposes the views defended by Kassowitz[3] that the metabolism in smaller animals is more intense than in the large animals and that there is no relationship between the metabolism and the body-surface.[4] Schlossmann maintains that atrophic infants have a higher metabolism per unit of body-surface than normal infants, but that this points to the correctness of the Rubner law, since with these infants the relation between body-surface and body-weight is abnormal. As he made no measurements of the body-surface of these infants—a procedure that necessitated an enormous amount of work—no direct evidence is offered to show that there was an actual disproportion between the body-surface and the body-weight.

In a paper which appeared after the publication of Schlossmann's criticism, Kassowitz[5] sums up his arguments against the belief that the metabolism is proportional to the body-surface and using Schlossmann's own protocols criticizes adversely the latter's deductions.

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[1] Schlossmann and Murschhauser, Biochem, Zeitschr., 1911, 37, p. 23.
[2] Schlossmann, Deutsche med. Wochenschr., 1911, 37, p. 1633.
[3] Kassowitz, Allgemeine Biologie, Vienna, 1904, 3, p. 221.
[4] Schlossmann, Zeitschr. f. Kinderheilk., 1912–13, 5, p. 227.
[5] Kassowitz, Zeitschr. f. Kinderheilk., 1913, 6, p. 240.

In a paper which has only recently appeared[1] Schlossmann again discusses the degree of activity and the amount of work done by infants in crying. He strongly emphasizes the necessity of noting the degree of repose during the observation, either by the ocular method used by himself or the graphic record devised in this laboratory. Unfortunately at the time this paper was written, Schlossmann had not been able to compare the two methods.

Two later communications by Schlossmann and Murschhauser[2] on the metabolism of fasting infants have particular significance in connection with this report, as they discuss the ideal conditions for obtaining the basal metabolism.

Using a Pettenkofer-Voit respiration apparatus[3] in the Kaiserin Auguste Victoria-Haus in Charlottenburg, Birk and Edelstein[4] studied the respiratory exchange of a healthy, new-born infant weighing 3.2 kilograms and having a length of 50 cm. The infant was completely wound in cotton wool so as to keep the body-temperature at a normal level. Although he was removed from the respiration chamber several times during the day, the infant remained in the apparatus for the greater part of the 24 hours. On the second day the carbon-dioxide production per 24 hours was 55.6 grams, or 18.2 grams per kilogram; on the third day the total amount was 47.59 grams, or 15.76 grams per kilogram per 24 hours. The authors criticize the use of short experiments with a respiration apparatus by which the oxygen consumption can be determined and the respiratory quotients calculated, but they express regret that with their method the oxygen consumption can not be determined.

In a study made by Carpenter and Murlin of the energy metabolism of pregnant women before and after the birth of the child,[5] the energy metabolism of three new-born infants was also found per unit of weight and per unit of body-surface. The values were obtained by subtracting the measured metabolism of the mother from that of the mother and infant.

The metabolism of an atrophic infant was studied by Niemann,[6] who used a Pettenkofer-Voit respiration apparatus in the children's clinic of the University of Berlin. The observation continued 6 days, the infant remaining in the chamber the greater part of each day. The measurements of the carbon-dioxide production on the basis of 24 hours are given in table 9. When these results are computed on the basis of carbon dioxide produced per square meter of body-surface, using the formula of Meeh and the constant 11.9, the author finds that this infant with an average body-weight during the 6 days of 3.28 kilograms had a body-surface corresponding to 0.2626 square meter, and that the carbon-dioxide excretion per square meter of body-surface was 18.5 grams per hour.

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[1] Schlossmann, Monatsschr. f. Kinderheilk., 1913, **12**, p. 47. See also Am. Journ. Diseases of Children, 1913, **6**, p. 15.

[2] Schlossmann and Murschhauser, Biochem. Zeitschr., 1913, **56**, p. 355, *ibid.*, 1914, **56**, p. 483.

[3] Bahrdt and Edelstein, Jahrb. f. Kinderheilk., 1910, **72**, p. 43.

[4] Birk and Edelstein, Monatsschr. f. Kinderheilk., 1910, **9**, p. 505.

[5] Carpenter and Murlin, Arch. Internal Med., 1911, **7**, p. 184.

[6] Niemann, Zeitschr. f. Kinderheilk., 1913, **6**, p. 375.

TABLE 9.—*Results of an experiment with an atrophic infant* (Niemann).

Day.	Carbon-dioxide production per day.	Average temperature of air.
	grams.	°*C.*
1	108.0	20.5
2	110.4	20.0
3	117.6	21.0
4	115.2	21.0
5	120.0	21.0
6	127.2	21.0
Maximum	127.2	....
Minimum	108.0	....
Average	116.4	....

The metabolism of another atrophic infant was studied in the Universitäts-Kinderklinik, Berlin, by Frank and Wolff.[1] Using the Pettenkofer-Voit respiration apparatus modified by Rubner, they made two series of experiments of 4 days each. The average values for carbon dioxide are given in table 10. The authors especially comment upon the unusually high figures for the carbon-dioxide excretion and attempt to explain them by the disturbance between the computed body-surface and body-weight and the effect of a protein-rich diet, but expressly maintain that muscular activity played no rôle, as the infant, except on the first day, was "*sehr ruhig.*"

TABLE 10.—*Average carbon-dioxide excretion in experiments with an atrophic infant* (Frank and Wolff).

	Period I.	Period II.
Total 24 hours	127.61	148.81
Per hour	5.317	6.151
Per kilogram per 24 hours	34.44	38.95
Per kilogram per hour	1.435	1.623
Per square meter per hour	18.76	21.26

Bahrdt and Edelstein[2] also report an experiment with an atrophic infant, in which they used the respiration apparatus in Langstein's laboratory in the Kaiserin Auguste Victoria-Haus. The observation was made in three periods of four days each. In the first and last periods, the infant remained inside the chamber for the greater part of the 24 hours, being removed periodically, as is customary in experiments with this type of apparatus. Their final conclusion was that the heat-production of atrophic infants can be abnormally high aside from any effect which the environmental temperature or the body activity may have upon it.

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[1] Frank and Wolff, Jahrb. f. Kinderheilk., 1913, **78**, p. 1.

[2] Bahrdt and Edelstein, Festschrift Dr. Otto L. Heubner, Berlin, 1913.

Finally the direct calorimetric and gasometric researches of Howland[1] in Lusk's laboratory should be especially noted. In discussing the calculation of the body-surface, Howland cites the use of the factor 12.3 as a constant for infants, but we are not aware of any writers who have previously used this factor. The experiments were made with the respiration calorimeter[2] at the Cornell University Medical College in New York. Three infants under one year of age were studied and ocular observations of the activity of the infants were recorded.

Howland's experiments were subsequently published in detail and the results more fully discussed.[3] In this paper the relationship between body-surface and body-weight is extensively treated and the various factors and formulas are considered. A curve is proposed which is represented by the algebraic expression $y = mx + b$, in which y is the surface area of the infant, x the weight of the infant in grams, m the constant 0.483, and b 730 sq. cm.

TABLE 11.—*Heat-production of infants, directly and indirectly measured, as reported by Howland.*

Subject.	Food.	Calories per square meter per day.		Difference (per cent).
		Measured.	Calculated.	
Child 1	Ordinary	1,046	1,084	2
		1,113	1,174	
		1,196	1,164	
Do	Nutrose added	1,218	1,179	3
Do	do	1,204	1,180	Less than 1
		1,235	1,212	
		1,181	1,250	
Do	Fasting	1,106	1,177	Less than 1
		1,226	1,156	
		1,301	1,243	
Child 3	Ordinary	858	793	2
		913	933	
Do	do	825	840	2

The last portion of the paper, which is of most significance, compares the direct and indirect computation of the heat-production of the infants observed. This comparison is of such value to workers in metabolism that it is given here in table 11. The agreement between the heat-production as directly measured and as indirectly computed is striking, to say the least, and justifies for the present the utilization of the indirect method of computing the calorimetry of infants.

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[1] Howland, Proc. Soc. Exp. Biol. and Med., 1911, 8, p. 63; Hoppe-Seyler's Zeitschr. f. Physiol. Chem. 1911, **74**, p. 1.

[2] Williams, Jour. Biol. Chem., 1912, **12**, p. 317.

[3] Howland, Trans. 15th Int. Congress on Hygiene and Demography, Washington, 1913, **2**, p. 438.

BASIC PRINCIPLES.

Though Howland, using Lusk's calorimeter, has been eminently successful in experiments on the direct calorimetry of infants, experience with such researches in the Nutrition Laboratory has led us to believe that a type of calorimeter with less mass, less heat capacity, and probably not of the continuous-flow type could most advantageously be employed for the short periods necessitated by experiments with infants. Several types or modifications of calorimeters have been in process of testing for some time, and pending the satisfactory development, construction, and testing of an infant calorimeter with the qualifications referred to, we have actively undertaken the study of infant metabolism as determined by indirect calorimetry. In these observations we have devoted our energies to the accurate measurement, in relatively short periods, of the carbon dioxide produced and oxygen consumed by infants less than one year of age.

There is at present in America a strong movement toward the development of hospital clinics liberally endowed for scientific research and it is fair to assume that in the next decade the study of infant metabolism will be more actively prosecuted in this country than ever before. Clinicians with whom we have conferred have especially requested that in publishing the results of our observations we should discuss the gaseous metabolism of infants somewhat in detail. Accordingly at this point it seems desirable to define a few of the principles underlying the method of study. This is done, first, to make clear the methods and technique used in our investigation; and, second, to serve as a guide for those clinicians or experimenters who are interested in actively following this line of research.

THE RESPIRATORY QUOTIENT AND ITS SIGNIFICANCE.

The oxygenation of the blood—which, prior to the birth of an infant, was effected by the lungs of the mother—is after birth at once begun through the lungs of the infant. The oxygen is carried by the blood to the various tissues and there enters into the katabolic processes, oxidizing the protein, fat, and carbohydrates. The resulting carbon dioxide is carried by the blood to the lungs and thence excreted into the air which passes though the lungs in respiration, while the partially oxidized nitrogenous products resulting from protein disintegration are excreted through the kidneys. With normal life both the carbohydrates and fat of the body-material are converted into carbon dioxide and water; protein, also, is in large part changed to carbon dioxide and water, the nitrogenous portion being excreted in the urine in the form of urea, uric acid, and allied compounds.

The chemical composition of the chief constituents of the body has been determined by analysis and is given in table 12. These values represent the average of a large number of analyses, and have been extensively used in computations of the indirect calorimetry of men.

TABLE 12.—*Chemical composition of the constituents of the body.*[1]

Body material.	N.	C.	H.	O.	Mineral matters (including S.).
	per cent.	*per cent.*	*per cent.*	*per cent.*	*per cent.*
Proteins	16.67	52.80	7.00	22.00	1.53
Fat	....	76.10	11.80	12.10	....
Carbohydrate (glycogen)	....	44.40	6.20	49.40	....

[1] While these values were determined on carefully isolated and purified materials obtained from the animal body, they may be considered as approximate values for all proteins and fats.

Innumerable analyses have been made of the ordinary food substances, but the composition of starch, cane sugar, glucose, and lactose can be computed from the chemical formulas directly. For the composition of normal fat, the average values given by Koenig are ordinarily used.[1] When these substances are burned inside the body, a definite volume of oxygen combines with their carbon and hydrogen to produce carbon dioxide and water. The amount of carbon dioxide produced per gram of a substance, the amount of oxygen required for the oxidation, and the total heat evolved can be determined exactly by burning a known amount of various fats and carbohydrates outside of the body, as, for instance, in a calorimetric bomb.

The carbon dioxide is excreted in a gaseous form, while the water may be excreted through the kidneys, vaporized through the lungs and skin, or added to the residual water always present in the body. Since there is so large a storage of water in the body, it is obviously impossible to distinguish between water formed by the oxidation of organic material and water existing preformed in the body, but the relationship between the oxygen consumed and the carbon dioxide produced has a great physiological value and plays an important rôle in indicating the *character* of the material burned in the body. The importance of this relationship was early recognized by Pflüger and the ratio was designated by him as the "respiratory quotient."

The theoretical respiratory quotient for the combustion of a pure substance of definite chemical composition may be easily computed. If we consider, for example, one of the chief foods of an infant—lactose or milk sugar, with a chemical formula of $C_{12}H_{22}O_{11} + H_2O$—we see that the hydrogen and oxygen are present in the molecule in the exact proportions to form water. Since there is in the molecule sufficient oxygen to oxidize the hydrogen completely, the oxygen which enters into the combustion burns only the carbon. It is, of course, obvious that the complete combustion does not proceed in this sharply defined manner, but this alters in no wise the trend of our reasoning.

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[1] Koenig, Chemie der menschlichen Nahrungs- und Genussmittel, 3d ed., 1, p. 198.

The chemical reaction may be expressed as follows:

$$C_{12}H_{24}O_{12} + 12\ O_2 = 12\ CO_2 + 12\ H_2O$$

That is, for every 12 molecules of oxygen absorbed, there are produced 12 molecules of carbon dioxide. Accordingly, for every liter of oxygen absorbed, there is produced one liter of carbon dioxide, so that the volume ratio may be expressed:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2} = 1.00$$

We can say, therefore, that the respiratory quotient of lactose is 1.00. This is also true of all carbohydrates, including starch, cane sugar, levulose, and dextrose.

Furthermore, it can be computed from the molecular composition that 1 gram of human fat requires 2.844 grams of oxygen in its combustion and that as a result of the combustion 2.790 grams or 1,420.4 c.c. of carbon dioxide are produced. There is, therefore, an absorption of 1,990.8 c.c. of oxygen to form 1,420.4 c.c.[1] of carbon dioxide; hence the respiratory quotient would be:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2} = \frac{1420.4}{1990.8} = 0.713.$$

The calculation of the theoretical respiratory quotient of protein is less simple, owing to the fact that protein is only incompletely oxidized, a portion of the protein molecule being excreted unburned in the form of urea, uric acid, and allied compounds in the urine. The calculation of this quotient has been made in a number of ways by different writers on the subject, each assuming a somewhat different molecular composition for protein and each ascribing in turn various values to the unoxidized portion of the protein excreted in the feces as well as in the urine. Furthermore, observers differ as to what degree the sulphur of protein is oxidized, for unoxidized as well as completely oxidized sulphur may be found in the urine. The following calculation is taken directly from Loewy,[2] in which he assumes that 100 grams of fat-free, dry substance of flesh contain 52.38 grams of carbon, 7.27 grams of hydrogen, 22.68 grams of oxygen, 16.65 grams of nitrogen, and 1.02 grams of sulphur. The assumed apportionment after oxidation is given in table 13.

TABLE 13.—*Assumed apportionment of elements after oxidation.*

	C.	H.	O.	N.	S.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*
In the urine.....	9.406	2.663	14.099	16.28	1.02
In the feces......	1.471	0.212	0.889	0.37	0.00
Remainder......	41.500	4.400	7.690	0.00	0.00

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[1] Erroneously stated as 1,240.4 c.c. by Benedict, Am. Journ. Physiol., 1909, **24**, p. 348.

[2] Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4**, (1) p. 156.

In the combustion of 41.5 grams of carbon and 4.4 grams of hydrogen, 145.87 grams of oxygen are used. Deducting from this the 7.69 grams originally in the protein and not excreted in the urine or feces, 138.18 grams of oxygen additional are required. During the process of oxidation, 152.17 grams of carbon dioxide are formed. Reducing these values to volumes, we then have the ratio:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2}=\frac{77.39}{96.63}=0.801.$$

The oxygen required for combustion, the products of combustion, and the respiratory quotient for several typical materials have been calculated and are given in table 14.

Table 14.—*Respiratory quotients for protein, fats, and carbohydrates.*

Materials.	Oxygen required to oxidise 1 gram.		Produced in the oxidation of 1 gram.			Respiratory quotient $\frac{CO_2\text{ c.c.}}{O_2\text{ c.c.}}$
			Carbon dioxide.		Heat.	
	Weight.	Volume.	Weight.	Volume.		
	grams.	*c.c.*	*grams.*	*c.c.*	*cal.*	
Starch..........	1.185	829.3	1.629	829.3	4.20	1.000
Cane sugar......	1.122	785.5	1.543	785.5	3.96	1.000
Milk sugar[1].....	1.066	756.2	1.466	746.2	3.75	1.000
Animal fat......	2.876	2013.2	2.811	1431.1	9.50	0.711
Human fat......	2.844	1990.8	2.790	1420.4	9.54	0.713
Protein[2]........	1.367	956.9	1.520	773.8	4.40[3]	0.809

[1] These values apply likewise to dextrose and levulose.

[2] While this computation is based upon meat protein, the values will be essentially the same for all proteins. These values represent quantities found when burning protein not in a calorimetric bomb, but in the animal body.

[3] The heat of combustion of protein averages 5.65 calories per gram; deducting the unoxidised material in the urine, the heat per gram would be 4.40 calories. For discussion of this point, see Atwater and Bryant, Storrs (Connecticut) Agr. Expt. Sta. Rept., 1899, p. 73.

The carbohydrates have a respiratory quotient of 1.00; fat in general, of 0.71; and protein of 0.81. From these factors, therefore, we can see that during inanition, when the subject is subsisting for the greater part upon body-fat and protein, the respiratory quotient would tend to approach 0.71. On the other hand, if a diet is taken consisting largely of carbohydrates, the respiratory quotient tends to approach 1.00.

Since the metabolism of the protein remains relatively constant from day to day and from hour to hour and is but a small proportion of the whole, the errors involved in its calculation are not of sufficient magnitude to influence seriously any deduction drawn from the results in which these calculations occur. Usually the disintegration of the protein is about 15 per cent of the total katabolism. Magnus-Levy[1] has calculated that if the remaining 85 per cent is wholly from carbohydrates, the respiratory quotient would be 0.971; if, on the other hand, the remainder of the energy is derived solely from fat, the respiratory quotient would be 0.722.[1] Under ordinary conditions, the respiratory quotient would lie between these two figures, and values above or below these points might reasonably be considered as due to faulty technique, to distinctly abnormal metabolism, or to a possible formation of fat from carbohydrate or carbohydrate from fat.

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[1] Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, **1**, p. 217.

It is thus clear that when the respiratory quotient is carefully determined, considerable light may be thrown upon the *character* of the materials burned in the body. It should be considered, however, that to determine accurately the respiratory quotient calls for an extraordinarily skilful technique, since any errors affecting either the determination of the carbon dioxide or the determination of the oxygen likewise affect the respiratory quotient.

The absolute values for the amounts of carbon dioxide exhaled and oxygen absorbed in a given time, usually 1 minute, 1 hour, or 24 hours, are also of importance in indicating the quantitative relations of the total katabolism. For example, it is possible to strike a daily balance from the amounts determined for 24 hours and show the adequacy or inadequacy of the ration for maintenance by determining or computing the carbon in the diet.

INDIRECT CALORIMETRY.

A number of physiologists have used the respiratory exchange to compute the total calorimetry by the method of so-called "indirect calorimetry,"[2] and obtained results of still more importance. The total katabolism may be apportioned between protein, fat, and carbohydrates by using the determination of nitrogen in the urine (protein katabolism) and the respiratory exchange. Since in calculating the materials katabolized in experiments with respiration calorimeters, it is generally assumed that all of the food materials are first transformed into similar substances found in the body, the calculation of the total energy may with propriety be based upon the values of body-protein, human fat, and glycogen. As each of these materials, when burned, supplies definite amounts of heat, the total energy resulting from the oxidation may be computed by multiplying the number of grams of each katabolized material by certain factors, that customarily used for protein being 5.65, or after deducting the potential energy in the urine, 4.4; for fat, 9.54; and for carbohydrates, 4.19.

Definite information regarding the calorific output of an infant is of great importance in studying infant nutrition in order that a calculation may be made of the amount of food required to provide a suitable quota of calories for the day. The caloric losses from the body, therefore, require careful consideration in studies of infant metabolism. With normal metabolism and normal digestion, the loss of unoxidized material in the feces and urine may be considered as essentially constant. The feces represent not merely the undigested residues of food but the epithelial débris, the residues of digested juices, and bacteria; with normal digestion, these remain essentially a constant percentage of the total amount digested.

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[1] Erroneously reported as 0.772 by Benedict, Am. Journ. Physiol., 1909, **24**, p. 351.

[2] This method is not to be confused with the usage of certain French writers who consider "indirect calorimetry" as indicating the computation of material consumed by noting the weights of food eaten, excreta, and gain or loss of body-weight.

It is not the loss of energy through the urine and feces, however, that is of special interest in studying infant metabolism, but the losses resulting from the katabolism of materials in the body, namely, the loss through the combustion of organic substances by virtue of the oxygen taken into the system and there combined with carbon and hydrogen to form carbon dioxide and water. The carbon dioxide thus formed has been considered so close a measure of the total amount of material burned that for years it served as the index of the total combustion of the materials in the body. It may be computed from the data given in table 14 that if the combustion in the body were exclusively of carbohydrate, the production of 1 liter of carbon dioxide would be equivalent to the liberation of approximately 5.05 calories of heat. If, on the other hand, the carbon dioxide resulted exclusively from the combustion of fat, it can be computed that 1 liter of carbon dioxide corresponds to 6.7 calories of heat.

While with an infant on a normal diet the proportions of protein, fat, and carbohydrate in the oxidized material may remain relatively constant, it is certainly true that in pathological cases these proportions may be greatly disturbed, and the calorific value of the carbon dioxide may vary considerably with different conditions. Inasmuch as information regarding the diet and treatment of infants is more especially required in pathological conditions, it is evident that a better method for estimating the total heat output than by the carbon-dioxide excretion is to be desired. If the relationship between the heat-output and the oxygen consumption is closely examined, it will be seen that the ratio is much more constant than is the ratio between the carbon dioxide and the heat. Thus, for every gram of lactose burned, 1.066 grams of oxygen are consumed, each gram of oxygen thus used being equivalent to 3.51 calories of heat. Likewise, for every gram of fat burned, 2.85 grams of oxygen are consumed, each gram of oxygen resulting in the production of 3.35 calories of heat. It will be seen from these figures that while the calorific equivalent of carbon dioxide varies some 25 per cent according to whether carbohydrate or fat is burned in the body, the calorific equivalent of oxygen varies only about 6 per cent. It is clear, therefore, that the best measurement of the caloric output of the body is the amount of oxygen consumed rather than the amount of carbon dioxide produced.

With modern apparatus it is possible to arrive at an even more exact knowledge of the energy output by determining both the oxygen consumption and the carbon-dioxide production and calculating the respiratory quotient. Zuntz, to whom we are especially indebted for the introduction of this method for computing the heat output, has painstakingly computed the calorific value of oxygen with different respiratory quotients, and these figures may be considered to-day as the best data that we have for the computation of the energy output from the measurement of the gaseous exchange. In the Zuntz laboratory, where practically all of the experiments carried out have been made upon adults with a mouthpiece or upon animals with tracheal fistulas, the determinations of the oxygen consumption are as accurate as are those of the carbon-dioxide production; consequently Zuntz has utilized the calorific values of oxygen, and these have been given in tabular form in one of the publications from his laboratory.[1] Knowing the respiratory quotient, the calculation of the calorific value of carbon dioxide is a simple one. Since, in our respiration apparatus, the carbon-dioxide determinations for short periods are even more exact than are the determinations of the oxygen, we give in table 15 the calorific equivalents of carbon dioxide with the varying respiratory quotients, particularly as this table will be used extensively in the computation of our own researches.

TABLE 15.—*Calorific equivalents of carbon dioxide.*

Respiratory quotient.	Calorific value of carbon dioxide.		Respiratory quotient.	Calorific value of carbon dioxide.		Respiratory quotient.	Calorific value of carbon dioxide.	
	Per liter.	Per gram.		Per liter.	Per gram.		Per liter.	Per gram.
	cals.	*cals.*		*cals.*	*cals.*		*cals.*	*cals.*
0.70	6.694	3.408	0.80	6.001	3.055	0.90	5.471	2.785
.71	6.606	3.363	.81	5.942	3.025	.91	5.424	2.761
.72	6.531	3.325	.82	5.884	2.996	.92	5.378	2.738
.73	6.458	3.288	.83	5.829	2.967	.93	5.333	2.715
.74	6.388	3.252	.84	5.774	2.939	.94	5.290	2.693
.75	6.319	3.217	.85	5.721	2.912	.95	5.247	2.671
.76	6.253	3.183	.86	5.669	2.886	.96	5.205	2.650
.77	6.187	3.150	.87	5.617	2.860	.97	5.165	2.629
.78	6.123	3.117	.88	5.568	2.835	.98	5.124	2.609
.79	6.062	3.086	.89	5.519	2.810	.99	5.085	2.589
						1.00	5.047	2.569

Since any form of indirect calorimetry must of necessity be somewhat speculative,[2] one must always rely for fundamental values upon direct heat measurements. Such measurements have been extensively made with men by Atwater and his associates at Wesleyan University, Middletown, Connecticut, where it was shown in experiments of long duration that the heat output as measured directly by the respiration calorimeter and the heat output as computed from the respiratory exchange agreed remarkably well. It should be pointed out, however, that these computations were based upon 24-hour periods. In certain experiments the computation has likewise been successful for periods as short as 6 hours, but it remained for Howland[1] to demonstrate with Lusk's calorimeter the complete agreement of the direct calorimetric measurements and of the computation from the gaseous exchange for short periods and particularly with an infant as subject.

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[1] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.

[2] It will be noted that in this publication the computation of the energy derived from protein is neglected and that the total energy output is computed only from the amounts of carbon dioxide and oxygen. The possible error in neglecting the protein has been computed by Magnus-Levy to be somewhat under 1 per cent, and as the determinations of nitrogen were not feasible in our studies, we have used the method of simple computation from the gaseous exchange as recommended by A. Loewy. (Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4**, p. 281. See also, Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, **1**, p. 207.)

Howland has, temporarily at least, forsaken direct calorimetric research, as he is not now supplied with a respiration calorimeter, but it is much to be hoped that these few observations, which imply such a remarkable agreement between the direct and indirect calorimetry, may be extended in the near future to cover other cases. Until later evidence disproves this assumption, workers in this field are perfectly justified in assuming that the comparison between direct and indirect calorimetry has been made with infants with more than ordinary scientific accuracy. This being the case, the field is open for making a large number of metabolism experiments with the respiration apparatus in laboratories and institutions where a respiration calorimeter for direct calorimetry is not available.

BASAL METABOLISM.

While the normal life of the infant is a relatively simple and constant one, yet it does include periods of muscular activity which vary greatly, the extremes ranging from perfect muscular repose during deep sleep to the violent exercise incidental to vigorous crying. As a result of these changes in muscular activity, the output of heat would likewise vary largely, with a minimum output during sleep and quiet and a maximum during the period of crying. An attempt has been made to find the average value for the heat output of an infant by experiments with 24-hour periods, thus securing an average for the life of the day; but when one considers that the difference between the heat output in complete muscular repose during sleep and the heat given off when the infant is crying vigorously may be as great as 60 or more per cent, it will be seen that this method of averaging does not furnish information with regard to the minimum metabolism.

With adults, the best condition which has been found for a basis of comparison has been when the subject was in complete muscular repose and in the so-called "post-absorptive" state, *i. e.*, when absorption of material from the alimentary tract had ceased, this being with adults generally 12 hours after the last meal. With an adult who is capable of a certain degree of muscular relaxation and repose, suitable experimental conditions can be obtained without great difficulty. With an infant this condition may only be approximated during sleep. It thus becomes necessary to consider seriously a fundamental change in the principle of studying infant metabolism and, instead of attempting to average the life during a 24-hour period, to use only selected periods with complete muscular repose.

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[1] Howland, Trans. 15th Int. Congress on Hygiene and Demography, Washington, 1913, 2, p. 451.

The muscular activity of infants is twofold: (1) internal muscular activity, consisting of muscular tonus, the movements of the organs of circulation and respiration, and possibly the processes of digestion; and (2) external muscular activity such as the movements of the limbs or vigorous body movement incidental to crying. The internal movements can be controlled only by minimizing the after-effects of digestion through the absence of food; the regular involuntary muscular activity of the respiratory and circulatory system and the muscular tonus can not be altered. On the other hand, the external muscular activities are at a minimum only during complete muscular repose, as in deep sleep. It is thus seen that the ideal conditions for studying the basal or minimum metabolism of infants would be the post-absorptive state—that is, sufficiently long after the last meal to insure that there was no longer an absorption of food materials from the alimentary tract, and during deep sleep when there is complete muscular repose. With very young infants, periods of complete muscular repose can not be expected for any great length of time, probably not for more than two successive hours.

The difficulties incidental to securing these conditions have prevented researches in this line for many months, if not years; the best method for obtaining them is still to be demonstrated.

We have, then, two factors to deal with, first, the heat elimination incidental to the specific katabolic stimuli of the food materials accompanying the digestion and absorption of food; and, second, the internal muscular activity of the infant. If the first of these factors can be eliminated, we have what may properly be termed the basal metabolism unaccompanied by extraneous muscular activity of any kind.

APPARATUS AND METHODS USED IN THIS RESEARCH.

Certain inherent difficulties in conducting experiments with infants have undoubtedly delayed the accumulation of a large amount of material in regard to infant metabolism. While researches have been actively prosecuted with domestic animals and with men for many years, the technique for the study of the metabolism of infants has been but slowly developed. Nevertheless, the natural difficulties incidental to the separation of the urine and feces of children have been for the most part overcome by careful technique, so that in hospital wards, at least, experiments on the total urine and fecal secretions can now be satisfactorily made.

But in a more extensive study of infant metabolism certain difficulties occur which are not encountered in a study of the metabolism of an adult. The infant is incapable of giving intelligent assistance in the experiment, neither can its muscular activity be controlled. Furthermore, in adult life, growth has been attained and the energy required is mainly for maintenance and for definite external muscular work, while infancy is a period of rapid growth, at least if normal metabolism is progressing; the infant, therefore, requires energy both for growth and for maintenance. While the amount of effective mechanical work is nil, nevertheless it has been clearly demonstrated that, during the periods of muscular activity incidental to the active life of the infant, there may be a large increase in the total metabolism. This simultaneous requirement for growth and for maintenance makes the study of infant metabolism a doubly complicated problem.

On the other hand, in studying the metabolism of an adult, one of the greatest difficulties we have to contend with is the complex life of the normal individual—the irregular or intermittent ingestion of food and the various degrees of muscular activity contributing to the sum total of the metabolic changes of the day. It is possible, by means of large respiration chambers, to approximate the normal life of a man of sedentary occupation or even with some degree of muscular activity, but it is practically impossible to duplicate the life of an ordinary individual with its different environments and activities. Consequently with adults it is necessary to secure periods for observation when the subject is without food in the stomach and when there is a minimum amount of activity. With an infant who spends the greater part of his day in the crib, the life complexes can be much more easily studied. The daily life is divided first into eating, sleeping, and crying; later, as the special senses and the intellect develop, to these divisions are added playing and exercise. Throughout the infantile period, therefore, the daily routine is monotonous and regular, with hours of sleep and waking time relatively constant. The diet of the infant is also unchanging in character, consisting for the most part of milk.

In summing up, we may say that the normal infant is more nearly constant as to its body activity, daily routine, and diet than the normal adult with his higher life complexes. The inability of the infant to assist materially in metabolism experiments, the difficulty of carrying out definite well-known tests with mathematical accuracy, and the impossibility of regulating the muscular activity must therefore be offset by this constancy in diet and daily routine. Hence it is by no means impossible to reproduce the daily routine of infants inside of a specially constructed chamber.

RESPIRATION APPARATUS.

In the Nutrition Laboratory and previously in the chemical laboratory of Wesleyan University, Middletown, Connecticut, various types of apparatus for studying the respiratory exchange have long been in the process of development. Since practically all of the earlier work had to do with the metabolism of men, there was very little demand for a small respiration apparatus. There are, however, many physiological laboratories and laboratories in hygienic institutes and medical clinics that wish to utilize an apparatus, not only for experiments with men but also with animals. Such a possibility has already been demonstrated, notably by Grafe[1] in Heidelberg and by Rolly[2] in Leipsic. A small apparatus, which is based upon the principle of the large respiration calorimeters used in this laboratory, has been here devised for experiments with men; this has already been described in detail.[3] While the fundamental principle has not been altered in any way, the apparatus has from time to time been modified and improved, and a cage or respiration chamber added, thus making observations possible with small animals and with infants. Its use with animals was first described by Benedict and Homans;[4] it was later referred to in a paper by Benedict and Talbot[5] as being used for observations with infants. In these earlier descriptions, it was stated that the apparatus had been only so far perfected as to permit the measurement of the carbon-dioxide excretion and did not permit the measurement of the oxygen consumption. Since these publications have appeared, a newer type of this apparatus has been devised and at least two investigations[6] have been reported from this laboratory in which the apparatus was used. The large number of respiration apparatus devised in the American and foreign laboratories make it practically impossible to contribute any fundamentally new features to the study of animal metabolism along this line. Nevertheless, as the main object in devising the apparatus used in this laboratory was to make it so flexible that it could be employed not only for men but likewise for infants and for large and small animals, a description of this later form seems desirable before further investigations are reported.

While the new feature in this modified apparatus is the direct determination of the oxygen consumption, opportunity is again taken here to emphasize strongly the importance of graphic records of the muscular activity in experiments with all classes of subjects, including not only men but infants and small animals, and also to emphasize the importance of the pulse-rate as an index of the intensity of the metabolism. Every respiration experiment conducted in this laboratory consists always of two parts, each indispensable to the other and each valueless without the other; first, the chemical division, *i. e.*, the measurements of the carbon-dioxide excretion and the oxygen consumption; and, second, the graphic records of the muscular activity or muscular repose and the pulse-rate. The main object of the apparatus and its accessories is, therefore, to give an accurate measurement on small animals or infants of the carbon dioxide produced and the oxygen consumed, and an interpretable record of the degree of muscular activity or repose, accompanied by pulse observations.

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[1] Grafe and Graham, Zeitschr. f. physiol. Chem., 1911, **73**, p. 7.

[2] Rolly and Rosiewicz, Deutsch. Archiv f. klin. Med., 1911, **103**, p. 58. See also discussion of Rolly's apparatus by Grafe, Abderhalden's Handbuch der biochemischen Arbeitsmethoden, 1913, **7**, p. 524.

[3] Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 156.

[4] Benedict and Homans, Journ. Med. Research, 1912, **25**, p. 409.

[5] Benedict and Talbot, Am. Journ. of Diseases of Children, 1912, **4**, p. 129.

[6] Benedict and Pratt, Journ. Biol. Chem., 1913, **15**, p. 1; Morgulis and Pratt, Am. Journ. Physiol., 1913, **32**, p. 200. At this point it is a pleasure to acknowledge the helpful assistance of Dr. S. Morgulis in developing the technique of determining oxygen with the apparatus.

The carbon dioxide produced by the animal is completely absorbed, the amount excreted being determined by the increase in weight of the absorbing vessels. Gas analyses, with their attendant difficulties of technique, are therefore unnecessary.

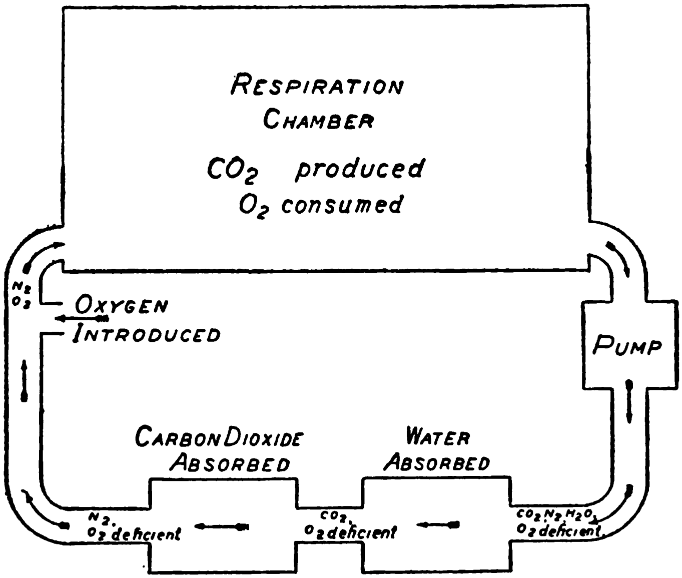

FIG. 1. Schematic outline of respiration apparatus.

The oxygen is determined directly by noting the amount it is necessary to introduce into the respiration chamber in order to secure the same volume of air in the chamber at the beginning and end of the experiment, making due allowance for changes in temperature, pressure, and water-vapor. While usually the amount of oxygen used is determined by allowing oxygen to flow into the respiration chamber from a previously weighed cylinder of the highly compressed gas and noting the loss in weight, it may likewise be accurately determined by passing the gas from a compressed cylinder through a carefully calibrated gas-meter which is submerged in water to prevent gross temperature fluctuations. The general plan of the apparatus is shown in the schematic outline given in figure 1.

As the infant gives off carbon dioxide and consumes oxygen, the air leaving the chamber is rich in carbon dioxide and water-vapor from the lungs and skin of the infant, contains a normal amount of nitrogen, and is deficient in oxygen. By means of a rotary pump, the air is carried from the chamber and forced through sulphuric acid, which absorbs the water, then through soda lime to remove the carbon dioxide; oxygen is next introduced and when the air returns to the chamber it is free from carbon dioxide and water and contains a normal percentage of nitrogen and oxygen.

A somewhat more elaborate scheme of the respiration apparatus, giving in considerable detail some of the special connections, may be seen in figure 2. The chamber, *C*, in which the infant remains, with its surrounding water jacket, *W*, *W*, for temperature control, is shown at the upper left-hand corner of the figure. The air leaves the chamber near the right-hand end at *O*, and is drawn by the rotary pump over a wet- and dry-bulb psychrometer, *Z*, which gives the amount of moisture in the air of the chamber. A can, *N*, filled with dry cotton-batting is also placed in the air-current between the blower and the chamber to act as a muffler. After leaving the exhaust side of the blower, *P*, the air is forced through an empty glass bottle, *A*, which serves as a trap should any back pressure take place and sulphuric acid be forced back from the water-absorbing vessels *B* and *C*. These latter vessels, which are of peculiar construction, were designed by Dr. H. B. Williams, of the department of physiology of Columbia University, and will hereafter be designated as "Williams bottles." The air passes along a pipe

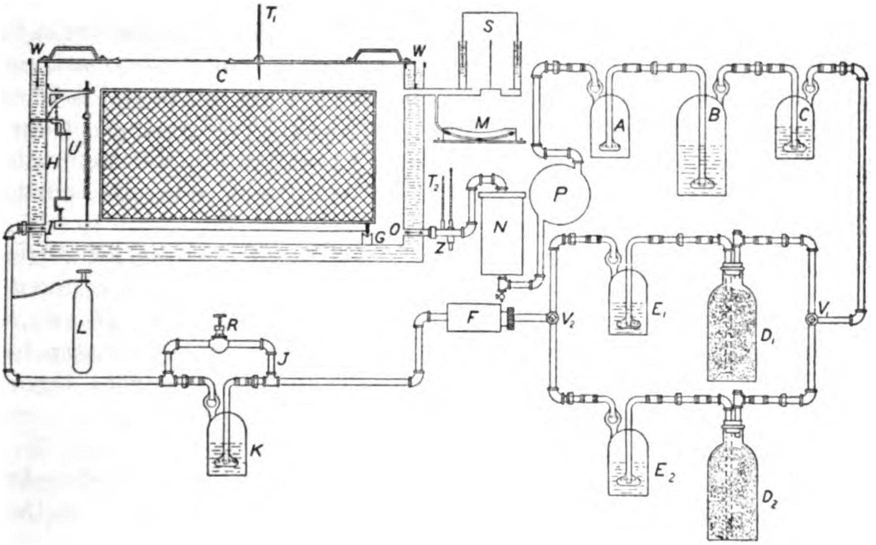

FIG. 2. Detailed scheme of respiration apparatus.

C, chamber; *W*, *W*, water jacket; *O*, outgoing air-pipe; *Z*, psychrometer; *N*, muffler; *P*, blower; *A*, acid trap; *B* and *C*, Williams water-absorbers; V_1 and V_2, 2-way valves; D_1 and D_2, carbon-dioxide absorbers; E_1 and E_2, air-dryers; *F*, sodium bicarbonate can; *J*, by-pass; *R*, valve; *K*, air moistener; *L*, oxygen cylinder; *I*, ingoing air-pipe; *S*, spirometer; T_1 and T_2, thermometers; *M*, manometer; *U*, spiral spring; *H*, pneumograph.

to a 2-way valve, V_1, where it may be deflected through either of the soda-lime bottles D_1 or D_2, in which the carbon dioxide is absorbed. Since the reagent must be somewhat moist to facilitate the absorption, it gives up water-vapor to the dry air-current, which must in turn be absorbed by sulphuric acid in the Williams bottles E_1 or E_2. The air next passes through the 2-way valve, V_2, and enters a small can, *F*, which contains dry sodium bicarbonate, the unweighable but noticeable sulphuric-acid odors being effectually removed by this means. The air then returns to the chamber through the by-pass *J;* or, if it is desired to moisten the air, the current can be deflected by closing the valve *R* in the by-pass *J*, so as to pass all of the air through distilled water in the Williams bottle, *K*. The air is now free from carbon dioxide and contains the water-vapor added in passing through *K*, but is still deficient in oxygen. This deficiency is made up by admitting oxygen from a cylinder, *L*, of compressed gas. The air thus enters the respiration chamber at *I*, somewhat moist and with approximately the normal percentage of oxygen.

Either series of absorbers may be used as desired, for if the air-current has been passing through the series D_1 and E_1 for a given experimental period, the air can be instantly deflected through the series D_2 and E_2, by turning simultaneously valves V_1 and V_2. As actually constructed, V_1 and V_2 are connected by a long rod, so that they may be thrown simultaneously by one movement of the hand.

Since the air-current is entirely closed, a small spirometer, *S*, is attached at the upper right-hand corner of the respiration chamber, thus providing for any expansion or contraction of the air. A thermometer, T_1, in the cover of the chamber, and a second thermometer, T_2, in the outgoing air, serve to indicate the temperature changes, while the manometer, *M*, shown below the spirometer, indicates the pressure of the air in the chamber.

By noting the increase in weight of the absorbers, D_1 and E_1 or D_2 and E_2, the amount of carbon dioxide absorbed is known. It is possible that the amount of water-vapor given up by D_1 to the dry air passing through it may be actually more than the amount of carbon dioxide absorbed, so that the bottle D_1 may lose in weight; on the contrary, the water-vapor given up is immediately absorbed by E_1, and hence the algebraic sum of the weight of the two bottles gives the weight of the carbon dioxide absorbed. Usually both bottles are weighed on a balance at the same time. The loss in weight of the cylinder *L* indicates the amount of oxygen absorbed, corrections being made for any variations in temperature and barometric pressure, or in the composition of the air inside the respiration chamber.

In figure 2 a general idea is given of the method of suspending the crib upon a stout spiral spring, *U*, at one end and a knife-edge, *G*, at the other. Alongside of the spring *U* is a pneumograph, *H*, the distension or contraction of which compresses the air inside of the pneumograph tube, thus transmitting, to a delicate tambour outside, a record of the slightest motion of the cage resulting from the movements of the infant. This method of obtaining a graphic record of the muscular activity is shown in more detail in figure 5 (p. 57).

While the general features of this apparatus have already been discussed in considerable detail,[1] with increased experience and with the facilities for modifying the technique to suit the conditions to be met, certain fundamentally important variations from the previously established technique have been found necessary. In this type of respiration apparatus the infant is lying in a crib inside of a small respiration chamber constructed of galvanized iron or copper and 77 cm. long, 25 cm. deep, and 37 cm. wide. To insure temperature control, the whole respiration chamber is surrounded by a water-jacket consisting of a second shell of galvanized iron or copper with a space of 5 cm. between the two shells. To withstand the pressure exerted by the weight of water, the two walls are separated by brass studs at approximately 5.5 cm. from each other, distributed all over the respiration chamber. This water jacket, which is filled with water to within a few centimeters of the top, acts also as a seal when the cover is placed upon the apparatus. Through this double-walled jacket pass the two pipes for the ventilating air-current, a pipe communicating with the spirometer or tension equalizer, a small pipe for the stethoscope tube, and a small pipe to connect the pneumograph of the body-movement registering device with the tambour outside. In the cover of the chamber are a window securely sealed and an opening for the air-thermometer.

In discussing the details of this apparatus, it seems best to follow in a general line the course of the ventilating air-current as shown in figure 2, from the time it leaves the respiration chamber until it returns. It should be stated at the outset that the general description of the apparatus previously referred to[1] gives a number of details that we can not enter into here, and that at this point we will discuss only such modifications as are essential for the successful prosecution of experiments with infants and small animals.

Psychrometer.—The psychrometer is essential for indicating the degree of moisture inside the respiration chamber. This is of value not only for the comfort or discomfort of the infant, but also for computing the amount of gas, particularly oxygen, inside the chamber at the end of the experimental period, since for these computations an exact knowledge of the water-vapor in the air is essential.

Formerly in the large respiration chambers it was necessary to aspirate a definite volume of air over pumice-stone drenched with sulphuric acid and note the increase in weight. Experiments carried out more recently have shown that in a specially constructed and very delicate psychrometer the depression of the wet-bulb thermometer can be measured with great accuracy and the amount of water-vapor in the air computed with an exactness sufficient for all practical purposes. The construction of this psychrometer, *Z*, is very simple. Two thermometers, each graduated in 0.1 degree and capable of being read with a lens to 0.01 degree, are placed in the air-circuit leading from the respiration chamber. The thermometer nearest to the chamber is the dry-bulb thermometer; around the bulb of the other thermometer is lightly attached a piece of fine linen which is continually kept moist with water drawn from a small reservoir by capillary attraction. By the use of the well-known psychrometric tables, it is possible to compute from the depression of the temperature the tension of the water-vapor, the degree of humidity, and the actual amount of moisture in the air. With the large respiration calorimeters, this has been carefully controlled both by the aspirator method—that is, by the aspiration of a certain volume of air over pumice-stone—and more particularly by the use of the extraordinarily ingenious and accurate psychrometer[1] of Dr. Klas Sondén of Stockholm.

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[1] Benedict, *loc. cit.*

The wet- and dry-bulb psychrometer as thus constructed gives most satisfactory results. It is, however, of the highest importance to make sure that the cloth around the wet-bulb thermometer is kept thoroughly drenched with distilled water, also that the capillarity of the fiber is good, as otherwise the cloth may become partially dried and inaccurate results obtained. Prior to each experiment, the wet bulb is drenched by using an elongated medicine dropper filled with distilled water.

Muffler.—Since a rotary pump is used to keep the current of air in motion, which rapidly draws in successive small portions of air, a puffing sound is produced which has proved somewhat disturbing to certain infants. To eliminate this, a small muffler, *N*, consisting of a brass can filled with cotton batting, is placed between the psychrometer and the blower.

Blower.—After experimenting with many different types of blowers, we have found the most satisfactory to be that furnished by the Crowell Manufacturing Company of Brooklyn, New York, under the specification No. O–D Rotary Compressor. This can be secured from the manufacturers in a surrounding iron box, which is suitable for an oil-immersion bath. It is a positive blower in that the air withdrawn from the chamber may be forced through a considerable number of layers of sulphuric acid and soda lime contained in suitable vessels. The blower (*P*) is connected by a leather belt to a small electric motor and can be provided with a safety clutch to prevent the reversing of the wheel through carelessness and the drawing over of sulphuric acid from the water-absorbers. This latter feature has been found of advantage, although the insertion of the safety trap (*A*) has prevented this. The speed of the blower may easily be altered by a simple lamp resistance, these blowers usually giving a suitable ventilation—not far from 35 liters per minute—when rotating at the speed of 270 revolutions per minute. Even with this rate of ventilation, it has been shown by careful experimenting, with a portable alcohol lamp placed in different parts of the chamber, that there is no draft which would be noticed by the infant. The fact that the relative humidity does not become unduly low is further proof that the infant is sojourning in an atmosphere approximately normal.

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[1] Sondén, Bihang till K. Svenska Vet.-Akad. Handlingar, 1891, **17**, p. 3; see also Meteorologische Zeitschr., 1892, p. 81.

Acid trap.—To prevent the possibility of sucking strong sulphuric acid into the delicate mechanism of the blower, an empty glass bottle (*A*) is inserted into the series. While almost any form of bottle can be used for this purpose, it has been convenient for us to employ an empty reversed "Williams bottle."

Water absorber.—The air leaving the respiration chamber contains a large amount of water-vapor from the lungs and skin of the infant and from the moisture of the incoming ventilating air-current. Before the carbon dioxide produced by the infant is absorbed, it is important to remove this water-vapor entirely from the air. The current is therefore first passed through two or more bottles containing concentrated sulphuric acid. Usually one large-sized Williams bottle (*B*) is sufficient to collect nearly all of the moisture, but this is followed by a second bottle (*C*), which retains the last traces of water-vapor.[1] To facilitate the handling of the bottles and to prevent breakage, they are usually inclosed in a small wire basket with a handle, by means of which they may be suspended directly from a hook on the arm of the balance. When these two Williams bottles are used, it is possible to retain the first bottle in the circuit until the acid has so far accumulated as to render it liable to be carried over mechanically into the second bottle. Indeed, 100 or 200 grams of water-vapor may be absorbed; it is fundamentally important, however, to note that the second Williams bottle must not increase in weight more than 15 grams before being renewed. As a matter of experimental routine, it has been found advantageous to replace the first Williams bottle each day with another which has previously served in the quantitative absorption of carbon dioxide, replacing these bottles with new ones every other day. The second Williams bottle should be controlled by weighing every few days.

Tubing and piping.—The Williams bottles, as well as the soda-lime bottles for absorbing the carbon dioxide, are fitted with short lengths of rubber tubing of good quality, to which are attached respectively male and female parts of ordinary garden hose couplings of the standard

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[1] The Williams bottles are made for us in Berlin by the Vereinigte Fabriken f. Laboratoriumsbedarf.

¾-inch size (approximately 16 mm. internal diameter). The couplings are therefore interchangeable with different forms of apparatus. With a standard rubber hose gasket, the couplings can be made air-tight by a simple twist of the hand. All of the piping throughout the apparatus is of standard ½-inch (16 mm. internal diameter) galvanized iron pipe.

Two-way valve.—In order to deflect the main air-current from one set of purifiers to the other, it is necessary to have a 2-way valve, but unfortunately this can not be purchased in the open market. For this purpose we have taken an ordinary 3-way ½-inch gas cock and soldered up one of the ports, then ground it again to fit the valve body. When properly done and the valve lubricated with a little cerate or vaseline, the result is very satisfactory. The valves V_1 and V_2 are of this type. A long steel rod connects these two valves so that by throwing the handle at one valve both valves are simultaneously closed and the air-current instantly deflected from one set of purifiers to the other.

Soda lime and containers.—The most effective absorbent for carbon dioxide that we have found is slightly moist soda lime. So important is the preparation of this reagent that we consider it fitting to republish the method here.

The soda lime is prepared in a round-bottom iron kettle, holding about 3 liters. For this purpose 1,000 grams of commercial caustic soda of good quality are dissolved in approximately 600 c.c. of water. When completely dissolved, 1,000 grams of finely pulverized quicklime are rapidly stirred into the hot lye and the stirring continued with a long-handled iron rod. The lime is immediately slaked, a large amount of heat and steam being given off. If the operation is carried on out of doors or under a good hood, soda lime may be readily made by unskilled labor.

For infants and for animals weighing not less than 3 to 5 kilograms the ordinary soda-lime containers are used (D_1 and D_2), these being wide-mouthed glass reagent bottles of the usual type. Each bottle contains 2 kilograms of soda lime, capable of absorbing not less than 75 grams of carbon dioxide, and weighs when filled about 4 kilograms. The moisture in the soda lime is essential to its efficiency, but the air after passing through the absorbent must again be dried by passing it through the Williams bottles E_1 or E_2.

Sodium-bicarbonate can.—In order to absorb the traces of acid fumes which may remain in the air after it has been carried through the Williams bottles, it is necessary to insert in the air-circuit a small can filled with dry sodium bicarbonate (F). This completely removes the acid fumes and does not affect the determination of the carbon dioxide or of the oxygen in any way.

Air-moistener.—With very small infants and with a fairly rapid flow of air, it is quite possible that the humidity inside the chamber may be too low for comfort and hence it is advisable to secure some means for rapidly and accurately moistening the air to a suitable degree. For this purpose a Williams bottle (*K*), containing pure distilled water, is placed in the circuit in such a manner that, by closing a valve in the by-pass, the entire air-current may be forced through the water in this bottle or as little thereof as may be desired.

Oxygen.—The direct determination of oxygen may be made either by weighing a small cylinder of gas (*L*) and noting the loss in weight during the experiment or by using an exceedingly delicate and accurate gas meter. Small cylinders of compressed oxygen which can readily be weighed may be secured from the Linde Air Products Company of Buffalo, New York. These cylinders weigh when filled about 3 kilograms and contain about 150 grams of oxygen with a purity of about 97 per cent. The oxygen supplied by this company is made from liquid air and consequently the residual gas, instead of being nitrogen, as has commonly been supposed, is as a matter of fact in large part argon,[1] so that to the volume of oxygen measured, about 1 per cent should be added for the argon.[2]

One of the greatest difficulties in using these cylinders has been the selection of a suitable valve, that furnished on the cylinder by the manufacturer being difficult to utilize owing to the high pressure under which these cylinders are filled. Formerly recourse was had to one of the numerous types of reduction valves, but a thorough test of these did not result in securing such a valve as would functionate properly for any long period of time. One or two types of needle valves have been found which are much less expensive and give a satisfactory closure. Such a needle valve is coupled to the exit of the cylinder, then closed, and the main valve on the cylinder is opened to its fullest extent. The issuing gas may then be very delicately regulated by means of the needle valve. With so high a pressure it is obvious that the packing around the main valve stem should be excellent, so as to give no opportunity for leakage of air. The valves may be tested by immersing the cylinder and valve under water or by weighing the cylinder carefully on a balance and then again an hour later, when any loss of oxygen will be instantly apparent.

Gas meter.—From many standpoints the use of a small weighable cylinder of oxygen is to be recommended. On the other hand there are certain advantages in favor of using an accurately calibrated gas-meter under such conditions as to preclude excessive temperature fluctuations. In our experiments with infants we have almost always employed a large cylinder of oxygen with a valve, conducting the gas through a carefully calibrated meter of the type devised by Bohr and manufactured by the Dansk Maalerfabrik of Copenhagen. This gas meter registers one liter for each complete revolution of the drum. Being constructed of britannia, it may without injury be completely immersed in water in a large aquarium vessel and so leveled as to be easily read. The corrections for temperature changes are minimized by this immersion in water. It is not possible, of course, to control the barometric fluctuations, and the meter readings should therefore be corrected not only for the average of the temperature fluctuations obtaining throughout the experimental period, but also for the average changes in the barometer. For relatively short periods this can best be done by using the temperature readings taken at the beginning and end of the period, and the barometer readings taken at the same time.

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[1] Claude, Comptes rendus, 1909, **151**, p. 752; Morey, Journ. Am. Chem. Soc., 1912, **34**, p. 491.

[2] For a discussion of this point, see Carnegie Inst. Wash. Pub. No. 187, 1913, p. 74.

The meter is calibrated by the method of weighing the gas delivered from an oxygen cylinder.[1] Many tests of this type of meter show that, when properly installed, it gives admirable results and when a long series of experiments is contemplated, its use is strongly to be recommended. A small, weighable cylinder of oxygen is required in either method, since such a cylinder is necessary for the calibration of the gas meter.

Temperature measurements.—In the dog apparatus, the volume of air inside the respiration chamber is about 250 liters; in the infant apparatus it is about 75 liters. It is clear, therefore, that correct temperature measurements of this air are necessary in order to determine the actual volume of the air in the chamber at the end of every experimental period. We have thus far employed two carefully calibrated mercury thermometers to measure the average temperature of the air in the chamber, one in the cover of the chamber (T_1), the other the dry-bulb thermometer of the psychrometer (T_2). While the two thermometers rarely read alike, their fluctuations in temperature are usually parallel; consequently, for lack of better measurement, the average of the readings of the two thermometers is taken as representing the average temperature of the air in the chamber. Experiments are now in progress seeking a better record of the average temperature of the air by means of electrical-resistance thermometers.

Temperature control of the respiration chamber.—The importance of temperature measurement has just been outlined, but it is likewise important to conduct the experiments so that the respiration chamber shall not be subjected to sharp and sudden fluctuations of temperature during the experimental period. It has therefore been found necessary to construct the water-jacket entirely around the chamber, except on the top. The space between the two metal walls is filled with water. During cold weather, with a mercury thermo-regulator and a small burner beneath, temperature control can be very readily secured. In the excessively warm days of summer, when the temperature of the laboratory is considerably higher than that of the chamber, it is necessary to place ice in the water-tank. The ice floating on the water melts and the cold current of water descends, thus tending to equalize the temperature of the whole system. By judicious use of ice, a reasonably good control of the temperature can be obtained, even in the warmest weather.

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[1] Benedict, Physical Review, 1906, **22**, p. 294.

Spirometer or tension equalizer.—Although an absolute temperature control is theoretically possible with this apparatus, thus securing a constancy in the apparent volume of the air in the closed system, it is practically impossible to prevent slight temperature fluctuations, and these, together with the unavoidable and uncontrollable fluctuations in barometric pressure, demonstrate the necessity for some form of tension equalizer which will insure atmospheric pressure in the chamber. For this purpose a small spirometer (*S*) is used. The spirometer regularly attached to the "universal" respiration apparatus is provided with sundry devices for graphically tracing the volume of each respiration and indicating the total ventilation of the lungs when employed with adults. When the infant or dog respiration chamber is employed, the spirometer is used solely as a tension equalizer and accordingly, in figure 3, only those parts are shown which are essential to its use under such conditions.

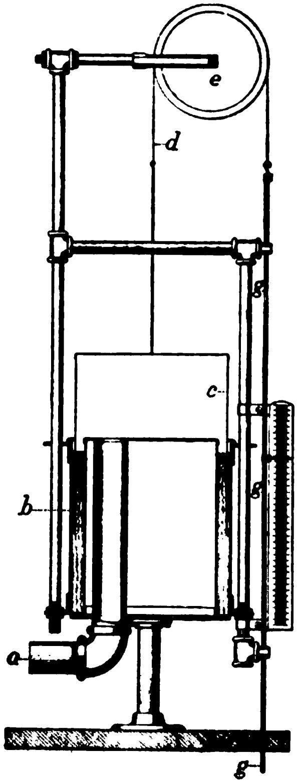

Fig. 3. Spirometer.
c, bell of spirometer; *d*, suspension cord; *e*, pulley; *g*, *g*, *g*, counterpoise; *b*, water or oil bath; *a*, air-pipe connecting with the respiration apparatus.

The upper part of this spirometer consists of a bell, *c*, constructed of very light copper or aluminium, suspended by a delicate cord, *d*, over a pulley, *e*, and counterpoised by a brass rod, *g*, *g*, *g*. This bell dips into a bath of water or oil in the annular space, *b*, between the two walls of the lower part of the spirometer. The pipe, *a*, connects directly with the respiration apparatus. By noting the position of the pointer on the millimeter scale at the right, the exact height of the bell can be seen at any moment. There is no particular compensation device used in connection with this spirometer to allow for the variations of the metal displaced as the bell enters or leaves the liquid; consequently there are, theoretically at least, slight alterations in the tension with the different positions so that it is advantageous to have the bell in nearly the same position at the beginning and end of each experimental period. It is our practice at the beginning of an experiment, after taking an initial reading of the height of the bell, to introduce a volume of oxygen approximately that which it is assumed that the infant will use during the period. The oxygen supply is then shut off and the bell gradually sinks. It is highly desirable that at the end of each period the bell should always be sinking, thus in part compensating for the slight alteration in tension. More recently we have found it advantageous to move the counterpoise rod, *g*, *g*, *g*, up or down by hand at the exact end of the period until the very delicate petroleum manometer indicates that there is no pressure. At this point the reading is taken.

Manometer.—The small oxygen consumption and the large volume of the respiration chamber with its accessory parts make the influence of slight changes in temperature and pressure of great moment in measuring the total oxygen consumption. Consequently it is essential to note the exact pressure inside the chamber. This is assumed to be atmospheric, but it is possible that the spirometer does not respond instantly to slight changes in pressure; accordingly it is more efficacious to use a very delicate manometer. This manometer (*M*) is of the type employed by Pettersson and Sondén in their gas-analysis apparatus and indicates the slightest alteration in atmospheric pressure. It consists of a glass tube bent in the form of an arc and containing a few drops of petroleum oil.

Balance.—The soda-lime bottles weigh, together with the Williams bottles, approximately 6 kilograms. The necessity for determining the amount of carbon dioxide produced in a half-hour period to within 0.01 gram makes it imperative to secure a balance with a large carrying capacity and extreme sensitiveness. Such balances we have as yet been able to obtain from only one manufacturer.[1] Fortunately they are quite inexpensive. These balances—of which there are many sizes, all of which have been tested in this laboratory—give very accurate results, for with a load of 10 kilograms 1 centigram is easily recorded. The balances are substantially mounted and surrounded by a glass case for protection against any disturbing drafts.

METHODS OF TESTING THE RESPIRATION APPARATUS.

The respiration apparatus just described, though extremely simple in principle, nevertheless has certain complexities. For experiments with infants, therefore, it is necessary to test completely the feasibility of the apparatus for measuring or indicating the several factors. For this purpose it is of prime importance to know that the apparatus is absolutely air-tight, so that when the cover is properly in place, no air can enter or leave the circulating air-current. Fortunately this is very readily tested in this type of apparatus.

TESTS FOR TIGHTNESS.

By a consideration of the diagram given in figure 2, it will be seen that the entire ventilating current is a closed circuit, the tension equalizer or spirometer allowing it to expand or contract according to the variations in temperature, pressure, or actual volume of air inside the system. By reading the millimeter scale over which the pointer from the counterweight of the spirometer bell passes, it can easily be seen whether or not the apparent volume of air in the chamber is altered during a test.

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[1] A. Sauter, Ebingen, Württemberg, Germany. The specifications are as follows: No. 7 II*a*, with aluminium beam and iron support, black enameled, in glass case, with carrying power 10 kilograms.

To make such a test, all of the various parts of the apparatus are connected as in an experiment with an infant, and the ventilating air-current started. After the first moment or two, during which the air throughout the whole system will be attaining equilibrium, the bell on the spirometer should reach a constant level, and thereafter the air should remain absolutely constant unless affected by changes in temperature or atmospheric pressure, these being indicated by the readings of the barometer and the two air thermometers. If the changes in the position of the spirometer bell can not be accounted for by temperature or barometer changes, there is obviously a leakage of air into or out of the system, usually the latter.

To test the efficiency of the apparatus and the absence of a defect in any individual part, especially when assembling the parts or when trying to locate a leak, a water manometer, consisting of two glass tubes connected at the bottom by a short bit of rubber tubing and attached to a suitable standard, is found advantageous, inasmuch as the slightest leak in any individual portion of the apparatus can readily be detected by applying pressure with a bicycle pump. When the apparatus has been properly installed, with accurately fitting rubber gaskets and connections, and suitable inspection given from time to time, there is no occasion for leakage, so that such an occurrence can invariably be ascribed to faulty technique. Since the experiments with infants instantly follow the test of the apparatus, the only disturbance thereafter being the removal of the cover which fits into the water seal, it will be seen that these tests should prove an admirable index of the condition of the apparatus during the experimental period.

Tests for the efficiency of the absorbing vessels.—The amount of carbon dioxide given out by the infant is determined by noting the increase in weight of the soda-lime vessel (D_1 or D_2) with its attendant Williams bottle (E_1 or E_2); the degree of absolute moisture in the air when it enters the soda-lime bottle and leaves the Williams bottle should be identical. If, however, the sulphuric acid in the Williams bottle, E_1 or E_2, following the soda-lime container, is allowed to accumulate water to such an extent that its efficiency as a water-absorber is somewhat less than that of the Williams bottle, C, preceding the soda-lime container, it is obvious that there would be a loss of water from the system as a whole and the amount of carbon dioxide thus measured would actually be too small. Conversely, if the air is not as dry before it enters the soda-lime bottle as when it leaves the Williams bottle following, there will be an undue increase in the weight of the carbon-dioxide absorbing system owing to the excess water absorbed. If the routine with the Williams and the soda-lime bottles is carried out as previously outlined, no difficulty is experienced, but it is advantageous occasionally to test the efficiency of the apparatus for absorbing carbon dioxide and water-vapor. Consequently, in testing for leaks it is advisable to weigh the sulphuric-acid and soda-lime vessels separately, and continue passing the air through the system for a half hour. Under these conditions, the loss in weight of the soda-lime vessel should of course be exactly counterbalanced by the increase in weight of the accompanying Williams bottle. With all of the experiments with infants here reported, this procedure was followed out every morning. It is needless to say that such precautions are no longer necessary, but inasmuch as this was the first year that the apparatus was used in the present form we considered it advisable to obtain this control before each experiment.

ALCOHOL CHECK TESTS.

The large respiration calorimeters in this laboratory have all been controlled by alcohol check tests as to their capability for measuring the carbon dioxide and the water-vapor produced, oxygen absorbed, and heat eliminated by the subject inside the chamber; we therefore hoped to secure as satisfactory control tests for this small respiration apparatus when used for infants. One of the greatest difficulties which immediately presented itself was that of developing inside the respiration chamber a known amount of carbon dioxide and absorbing a known amount of oxygen. A simple method for this would have been to place inside the respiration chamber an alcohol lamp and let it burn for several hours, noting the loss in weight of the lamp. It should be observed, however, that this respiration chamber is used for the most part during experiments with half-hour periods. We considered it unfair, therefore, to make an alcohol check experiment covering several hours and assume that the results showed that the apparatus would be equally as satisfactory for half-hour periods. The same problem arose in connection with the development of our first respiration apparatus for man,[1] and the difficulty was then overcome by burning a known amount of ether vapor. By reference to this earlier test, it will be seen that the special form of combustion chamber then used was perfectly comparable with the respiration chamber employed for infants. But the difficulties incidental to cooling the intense ether flame and making all the connections satisfactory rendered it practically impossible for us to carry out these tests in the hospital.

For many years an attempt has been made to secure some method for obtaining the actual amount of alcohol burned in a small lamp inside the respiration chamber in periods as short as 30 minutes. In lieu of this ideal test, we had to content ourselves with alcohol check tests of the following character:

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[1] Benedict, Am. Journ. Physiol., 1909, **24**, p. 372.

A small lamp, which was constructed from a 100 c.c. Erlenmeyer flask and partially filled with alcohol, was ignited and placed inside the respiration chamber. After a preliminary period of several minutes the air-current was deflected to the second set of purifiers, the proper readings taken, and several periods of 30 to 45 minutes each were carried out. Irrespective of the absolute amount of carbon dioxide absorbed by the soda lime or the total amount of oxygen admitted from the cylinder or measured by a meter, the relation between these two should be that obtaining in the perfect combustion of alcohol by oxygen. The respiratory quotient of alcohol, which can readily be computed, is found to be 0.666. Consequently the relationship between the amount of carbon dioxide absorbed and the amount of oxygen delivered through the meter or from the weighed cylinder was determined and if this was found to be approximately 0.666, it was assumed that the apparatus was functionating perfectly. As a matter of fact, such an alcohol check test was made usually once a week throughout the whole experimental year with values varying but little from the theoretical amount.

Deferring for the moment the description of the method of calculation, we give in table 16 the respiratory quotient for every alcohol check test carried out with this apparatus, the results being, for the most part, within the limits of experimental error.

TABLE 16.—*Respiratory quotients obtained in alcohol check experiments with the respiration apparatus for infants.*

Date.	Quotient.	Date.	Quotient.	Date.	Quotient.
1913.		1913.		1913.	
Jan. 9...	0.67	Apr. 10...	0.68	June 24...	0.68
15...	.68	17...	.67	25...	.66
16...	.68	29...	.67	Sept. 27...	.67
28...	.66	May 9...	.67	30...	.66
29...	.67	15...	.68	Oct. 4...	.66
Feb. 25...	.66	17...	.65	7...	.67
Mar. 1...	.68	23...	.66	9...	.66
14...	.69	June 5...	.66	9...	.67
21...	.68	14...	.70	Dec. 11...	.66
28...	.67	18...	.71	1914.	
Apr. 4...	.65	19...	.69	Jan. 1...	.65
				13...	.66

COMPLETE SHORT-PERIOD ALCOHOL CHECK TESTS.

Although the observations on infants reported in this publication were based upon the accuracy of alcohol check tests involving only the determination of the respiratory quotient, it is desirable to record at this point the development of a method which provided for the testing of this identical apparatus and the proof of its accuracy for measuring the results of half-hour periods after an amount of carbon dioxide had been developed approximately equal to that produced by an infant. From the experience with the large respiration chambers in the Nutrition Laboratory, it became increasingly evident that the discrepancies shown in the alcohol check tests for short periods were to be ascribed not to errors in the absorption of carbon dioxide or to the calculation of the amount of oxygen produced, but to discrepancies in the measurement of the small quantities of alcohol necessary for the control test. The alcohol required for producing (when burned inside the respiration chamber) an amount of carbon dioxide equivalent to that given off by a small infant corresponds to about 1.00 or 1.50 grams per half hour. To measure this with an accuracy of 1 per cent and to insure that the measurement represents not only the amount of alcohol introduced but the actual amount consumed, involves much experimental work. Mr. T. M. Carpenter, of the Laboratory staff, has recently conducted experiments in which this second difficulty has been overcome.

In these experiments a small piece of capillary copper tubing was carried through the walls of the respiration chamber by means of the tube commonly used for the stethoscope, and then bent upward to form a minute lamp. The exterior end of the copper tube was connected by capillary rubber tubing to a glass burette of very fine caliber which could easily be read to 0.01 c.c. The burette and the capillary rubber tubing were suspended by a cord running over a pulley, so that both the burette and the rubber tubing hung free in the air. When this burette was very slowly and gradually raised, alcohol flowed with great regularity through the copper tube into the chamber, where it burned quietly. By reading the level of the alcohol in the burette at the beginning and the end of any given experimental period, the absolute amount of alcohol introduced could be accurately determined. A small wooden pulley attached to the vertical upright of a Porter kymograph was used for raising the burette regularly. An extremely even elevation of the burette could be secured by adjusting the speed of the rotating fan so that the amount of alcohol introduced per half hour ranged not far from 1.00 to 1.25 grams. The whole apparatus is shown in figure 4, in which may be seen the copper tube extending through the two walls of the respiration chamber, the flexible rubber tubing, one end of which is attached to the copper tube and the other to the burette, and the wooden pulley and kymograph in position to raise the burette as desired.

When beginning the experiment, the lamp was lighted, the kymograph set in motion, and after the lamp had burned a few moments and regularity of combustion was assured, the cover was put in place. At the end of a preliminary period of not far from 15 to 20 minutes, the level of the alcohol in the burette was accurately read and the experiment proper began. Thereafter it was only necessary to read this burette accurately with a lens at the end of each experimental period of 30 to 40 minutes.

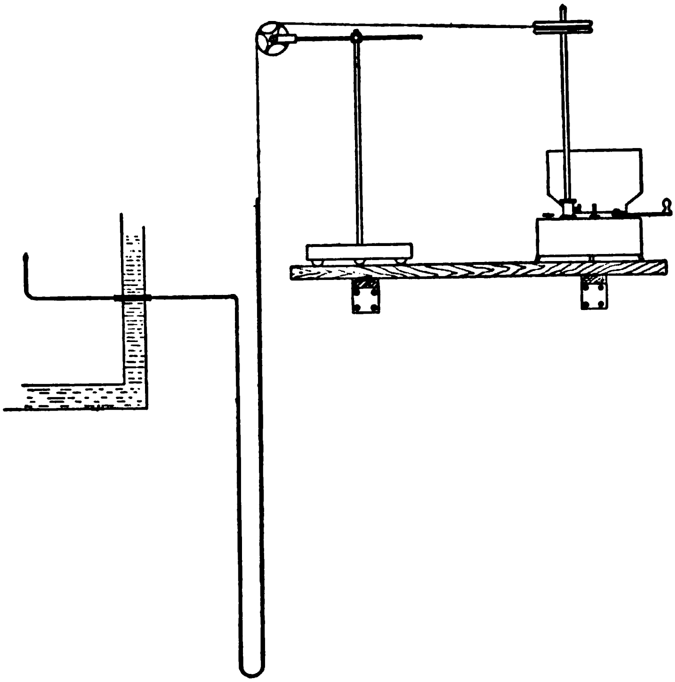

FIG. 4. Method of introducing alcohol in the alcohol check tests of respiration apparatus.

The ventilating air-current was passed through the chamber at the rate of approximately 35 liters per minute, and with a flame of this size and regularity in the introduction of alcohol the amount of carbon dioxide residual in the chamber at the end of each experimental period was usually very constant. Since, however, we were dealing with quantities of carbon dioxide amounting to 0.01 gram, it was necessary in this exceedingly exact work to determine the residual amount of carbon dioxide. This was obtained by drawing a sample of the air at the end of each period, and determining the amount of carbon dioxide by means of a modified[1] Pettersson-Palmquist gas-analysis apparatus, which permits measurements of 0.5 or less per cent of carbon dioxide to the third significant figure. Its manipulation is very simple and has been rapidly acquired by a number of workers in the laboratory. It should be stated that these residual analyses were not required in the observations on infants at the hospital, but were necessary only to secure the greatest degree of refinement in establishing the accuracy of the apparatus for measuring minute quantities of carbon dioxide and oxygen.

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[1] Anderson, Journ. Am. Chem. Soc., 1913, **35**, p. 162.

Method of computing the carbon-dioxide production.—In these alcohol check experiments, the carbon-dioxide production is found by weighing the soda-lime container with its accompanying Williams bottle, the increase in weight giving the amount of carbon dioxide produced during the period, assuming no change in the amount of carbon dioxide residual in the chamber. If extreme accuracy is desired, determinations of the residual amount of this gas are made as outlined above and any variations corrected for.

Method of computing the oxygen consumption.—The computation of the oxygen consumption is much more elaborate than that of the carbon-dioxide production, for while a rough measurement of the total oxygen consumption can readily be obtained by noting the loss in weight of the cylinder of gas or by reading directly the volume of gas passing through the Bohr meter, there are nevertheless a number of factors which affect these determinations, all of which must be taken into consideration. For example, the spirometer bell is at a certain height at the beginning of an experiment; if at the end this bell is either above or below this point, a correction therefor must be applied. If above, an excessive amount of oxygen has been added, and if below, the amount of oxygen is deficient. As each millimeter difference in the height of the spirometer bell corresponds to 23 c.c. of gas, the computation is very simple. On the other hand, if there is an increase in the temperature inside the chamber, the air expands and even if the spirometer bell is in the same position at the end of the period as at the beginning, less oxygen has evidently been introduced than if the temperature had remained constant. Conversely, if the temperature has fallen, more oxygen has been introduced. Similarly, if the barometric pressure has altered materially, it has likewise affected the introduction of the oxygen. For an exact computation of the amount of oxygen consumed by the subject, therefore, not only is it necessary to know the amount introduced from the weighed cylinder or through the Bohr meter, making due corrections on the readings of the gas meter for the factors of temperature and pressure and the mechanical factor of the meter itself, but likewise a correction for the alterations in the total volume of air inside the ventilating air system should also be made, since any alteration of the volume of the air inside the system represents a corresponding error in the oxygen introduced. For this purpose, it is necessary to note, first, the volume of air inside the chamber, which is roughly found by a simple computation; second, the temperature of the air in the chamber as shown by the readings of the two thermometers; third, the barometric pressure; fourth, the degree of humidity as obtained from the wet- and dry-bulb psychrometer, since the water-vapor in the chamber may also vary; and fifth, in exceedingly refined experimenting, the amount of carbon dioxide present in the residual air. The protocol of a single alcohol check test by this later quantitative method may serve to illustrate simultaneously the method of calculation and the accuracy of the apparatus.

DETAILS OF TYPICAL QUANTITATIVE ALCOHOL CHECK TEST.

Measurement of the residual carbon dioxide and oxygen.—This experiment consisted of two periods, the first from $11^h\ 30^m$ a. m. to $12^h\ 11^m$ p. m., and the second from $12^h\ 11^m$ p. m. to $12^h\ 51^m$ p. m. At the beginning and end of each period of the experiment, observations were made of the humidity conditions, the temperature of the apparatus, and the barometric pressure. By means of these observations and the determination of the carbon-dioxide content of the air in the chamber, the volumes of oxygen and nitrogen and of the carbon dioxide residual in the apparatus were obtained for the standard conditions of 0° C. and 760 mm. pressure. The observations made at the end of the first period are given in table 17.

TABLE 17.—*Observations at end of first period of alcohol experiment of October 9, 1913.*

Psychrometer: Dry bulb (t_1) 19.80° C.; wet bulb (t_2) 15.91° C.
Temperature at top of chamber (t_3) 21.63° C.
Temperature of apparatus (t_4): t_1 = 19.80° C.; t_3 = 21.63° C.; average, (t_4) 20.72° C.

Barometer:	Reading at end of period	767.05 mm.
	Tension of aqueous vapor in chamber	11.10 mm.
	Corrected barometer (p)	755.95 mm.

Residual carbon dioxide and oxygen:

		Logs.	
Total volume of apparatus	81.5 liters	= 91116	
Temperature of apparatus	$\frac{1}{1+0.00367\ t_4}$	= 96817	
Corrected pressure	$\frac{p}{760}$	= 99768	
Corrected volume $CO_2 + O_2 + N_2$		= 87701	= 75.34 liters.
Per cent CO_2 (by analysis) 0.098		= 99123	
Residual CO_2		= 86824	= 0.07 liter.
Residual $O_2 + N_2$			75.27 liters.

The temperature of the air in the chamber of the apparatus was not determined with absolute certainty. The thermometer placed in the top of the apparatus (t_3 in table 17) recorded temperatures which, because of the position of the lamp and the warm air rising to the bulb of the thermometer, were without doubt too high. The record obtained from the dry-bulb thermometer (t_1 of table 17) shows the temperature of the air immediately after it left the chamber. It is believed that the average of these two records (20.72° C. in table 17) gives an approximate value for the temperature of the air in the apparatus at the time the records were made and that the change in temperature from the beginning to the end of the period may by this means be obtained.

The barometer record in millimeters is also shown in table 17. From the psychrometer observations the humidity of the air within the apparatus is known. Deducting from the barometric pressure the tension of aqueous vapor (11.1 mm.) for this observed humidity, allowance is made for the volume of water-vapor present within the apparatus. The corrected barometer reading, p, is then used.

The total volume of the apparatus is 81.5 liters. In order to determine the total volume of water-free air under standard conditions of temperature and pressure, *i. e.*, 0° C. and 760 mm., to the logarithm of this total volume is added, first, a logarithmic factor for the average temperature recorded and, second, a logarithmic factor for the corrected pressure. These factors are obtained from tables which have been prepared for the purpose. The standard temperature reduction is represented by the formula $\frac{1}{1+at_4}$, t_4 representing the temperature of the apparatus. The reduction factor of pressure for standard conditions is obtained from the ratio $\frac{p}{760}$, in which p represents the corrected barometer. The total volume of oxygen and nitrogen is then obtained from the total volume of water-free air by deducting the volume of carbon dioxide as determined by the analysis with the Pettersson-Palmquist apparatus. No attempt is made to separate the volume of nitrogen, since the amount of this gas remains unchanged and the absolute amount of oxygen is not desired.

Measurement of the carbon dioxide absorbed and the oxygen admitted.—The records of the carbon-dioxide production and oxygen consumption for the first period of the experiment are given in table 18. The carbon

TABLE 18.—*Carbon dioxide absorbed, oxygen admitted, and alcohol burned in the first period of alcohol check experiment.*

Oxygen admitted.[1]		*Alcohol burned.*	
Weights of oxygen cylinder:		One gram 92.56 p. ct. absolute alcohol yields 1.769 gm. CO_2 and requires 1.930 gm. O_2.	
Start	3408.41 gm.		
End	3405.00 gm.		
O_2 =	3.41 gm.		
Impurity correction	−.01 gm.	Burette readings:	
Spirometer correction	−.03 gm.	11^h 30^m a.m.	0.590 c.c.
Total O_2 =	3.37 gm.	12 11 p.m.	2.770 c.c.
Carbon dioxide absorbed.		Difference	2.180 c.c. at 21.05° C. = 2.169 c.c. at 15.6° C.
Weights of absorbers, G+44:		2.169 c.c. (sp. g. 0.81576) = 1.769 grams (C_2H_5OH).	
End	5125.90 gm.	1.769 × 1.769 = 3.13 gm. CO_2 produced.	
Start	5122.78 gm.	1.769 × 1.930 = 3.41 gm. O_2 used.	
CO_2 =	3.12 gm.		

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[1] The calculations are here made on weight. For a method of determining the oxygen consumption by volume, see Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 181.

dioxide absorbed from the ventilating air-current was determined from the amount collected in the absorbing vessels, which were weighed at the beginning and end of each period. The amount of oxygen admitted to the apparatus was found from the change in weight of a cylinder of oxygen, which was also weighed at the beginning and end of each period, correction being made for the known impurities contained in the oxygen. Correction was also made for the change in volume of the spirometer, which, in the period represented by table 18, rose 1 mm. corresponding to 23 c.c. or 0.03 gram of oxygen. This, for convenience, is deducted from the corrected amount admitted from the cylinder.

Measurement of the alcohol burned and the calculation of the products of combustion.—The records of the alcohol burned and the calculation of the products of the combustion during the first period of the experiment are also given in table 18. The alcohol used in this experiment was 92.56 per cent ethyl hydroxide by weight, the combustion producing 1.769 grams of carbon dioxide for each gram of alcohol burned and requiring 1.930 grams of oxygen for the oxidation. The readings of the burette at the beginning and end of the period were respectively 0.590 c.c. and 2.770 c.c. at the average temperature of 21.05° C., or 2.169 c.c. at 15.6° C. The multiplication of this amount by the specific gravity at 15.6° C. (0.81576) gives 1.769 grams as the weight of alcohol burned. This amount, in turn multiplied by the factors 1.769 grams for carbon dioxide and 1.930 grams for the oxygen, gives respectively the theoretical amounts of carbon dioxide produced and oxygen consumed as a result of the combustion.

Comparison of the theoretical amounts of carbon dioxide produced and oxygen consumed with those measured by the apparatus.—The amounts of carbon dioxide produced and oxygen used as measured by the apparatus are found by correcting the amounts of carbon dioxide absorbed and the oxygen admitted for the change in the residual amounts present in the chamber. Comparison of the amounts found with the theoretical amounts as calculated from the weight of alcohol burned shows that for the entire experiment 98.7 per cent of the carbon dioxide produced was measured and 100 per cent of the oxygen used. The comparison is given in table 19.

As supplementary evidence on the alcohol check tests, measurements made in four other experiments with the baby respiration apparatus and one check test of two periods with another respiration apparatus of exactly the same type but used for dogs are presented in table 20. In considering the data for the experiment with the dog respiration apparatus, it should be stated that the volume of air in the chamber is over three times as large as the volume of air in the baby respiration apparatus; hence the errors incidental to accurate oxygen determinations are greatly magnified. In spite of this, however, it can be seen that the results for both forms of apparatus are very satisfactory, showing that measurements having a high degree of accuracy may be secured with either.

At this point emphasis should be laid upon the necessity of selecting a chamber of suitable size for the animal or the individual to be studied. The chamber having the smallest inner dimensions compatible with the comfort of the subject is to be preferred.

TABLE 19.—*Summary of measurements in alcohol check test of October 9, 1913.*

Time.	Carbon dioxide.			Oxygen.			Respiratory quotient.	Carbon dioxide.	Oxygen.
	Residual in chamber.	Carbon dioxide produced.		Residual in chamber.[1]	Oxygen used.				
		Found.	Theory.		Found.	Theory.			
First period.	*gram.*	*grams.*	*grams.*	*liters.*	*grams.*	*grams.*		*p. ct.*	*p. ct.*
$11^h 30^m$ a.m.	0.20	....	....	75.30	....	....	....	....	.....
$11^h 30^m$ a.m. to $12^h 11^m$ p.m.	.15	3.07	3.13	75.27	3.41	3.41	0.65	98.1	100.0
Second period.									
$12^h 11^m$ p.m. to $12^h 51^m$ p.m.	.20	2.96	2.98	75.18	3.25	3.25	.66	99.3	100.0
Total...	....	6.03	6.11	.....	6.66	6.66	.66	98.7	100.0

[1] Residual oxygen + nitrogen.

TABLE 20.—*Summary of measurements in alcohol check tests of the baby respiration apparatus and the dog respiration apparatus.*

Date.	Apparatus and time.	Carbon dioxide produced.		Oxygen used.		Respiratory quotients.	Percentage found.	
		Found.	Theory.	Found.	Theory.		Carbon dioxide.	Oxygen.
1913.	Baby.	*gm.*	*gm.*	*gm.*	*gm.*			
Sept. 30	$2^h 23^m$ p.m. to $2^h 53^m$ p.m.	2.20	2.22	2.44	2.42	0.655	99.1	100.8
	2 53 3 23	2.24	2.30	2.49	2.51	0.655	97.4	99.2
	3 23 3 49	1.88	1.93	2.05	2.10	0.655	97.4	97.6
	Baby.							
Oct. 4	$12^h 49^m$ p.m. to $1^h 20^m$ p.m.	2.33	2.31	2.57	2.52	0.660	100.9	102.0
	1 20 1 52	2.15	2.19	2.39	2.39	0.655	98.2	100.0
	Baby.							
Oct. 7	$1^h 42^m$ p.m. to $2^h 18^m$ p.m.	2.70	2.76	2.94	3.01	0.665	97.8	97.7
	2 18 2 54	2.66	2.69	2.87	2.93	0.670	98.9	98.0
	Baby.							
Oct. 9	$3^h 18^m$ p.m. to $3^h 58^m$ p.m.	2.65	2.61	2.86	2.85	0.675	101.5	100.4
	3 58 4 38	2.58	2.64	2.82	2.88	0.665	97.7	97.9
	Dog.							
Sept. 26	$8^h 53^m$ a.m. to $9^h 33^m$ a.m.	2.92	2.99	3.22	3.26	0.660	97.7	98.8
	9 33 10 13	2.79	2.83	3.06	3.09	0.665	98.6	99.0

METHOD OF DETERMINING THE DEGREE OF MUSCULAR REPOSE.

The intimate relationship between minor muscular activity and metabolism was soon recognized in experimenting with men in the large respiration calorimeter at Wesleyan University, Middletown, Connecticut, and all of the earlier publications of researches with this apparatus accentuate the importance of having a regular life routine throughout the experimental period. The first attempt to secure such regularity was the preparation of a program for each experiment, to be rigidly adhered to by the subject. This was followed by a record, made directly on the protocol sheets, of both the major and minor muscular movements which were noted by the physical observer through the window of the respiration calorimeter—a routine that was carried out for a number of years in all of the experiments.

In the later experiments made at the Nutrition Laboratory in Boston, a pneumograph was placed about the chest of the subject, primarily to record the respiration and the pulse-rate. These curves showed not only the rise and fall of the chest in respiration, but also any other muscular movements of the subject. This record was the first step towards a graphic representation of muscular activity during metabolism experiments, and played a very important part in an extensive research on diabetes[1] in comparing the metabolism of normal individuals and diabetics.

APPARATUS USED IN THE RESPIRATION EXPERIMENTS.

The success of this method of graphic registration in experiments on man led to the development of a method for the registration of the movements of animals. The first apparatus used in this laboratory was that devised by Benedict and Homans,[2] in which one end of the cage containing the animal was supported by a knife edge and the other by a stout spiral spring; the slightest change in the center of gravity of the animal changed the tension upon the spiral spring, causing the suspended end of the cage to move up or down. By means of a rod connected with the end of the cage and carried out through the top of the chamber, the movements of the cage were traced directly upon a kymograph. The mechanical difficulties of passing this rod through the cover of the chamber, which must be air-tight, were overcome, but later a tube pneumograph was substituted. This pneumograph was attached to the cage and the wall of the chamber parallel to the spiral supporting the free end of the cage. The slightest lengthening or shortening of the pneumograph produced a change in the tension of the confined air, these varying air tensions being transmitted by a tube through the walls of the chamber to a delicate tambour and pointer which gave graphic records on a kymograph drum.

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[1] For a reproduction of these curves, see Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910.

[2] Benedict and Homans, Am. Journ. Physiol., 1911, **28**, p. 29.

This method proved admirable for use with animals and was subsequently added by us to the respiration apparatus for infants. We have in an earlier publication pointed out the advantages of securing such records and have likewise given some characteristic tracings.[1]

The same principle has been applied to the bed calorimeter in use in the Nutrition Laboratory.[2] For this apparatus, however, we have recognized the fact that while infants when moving usually change the center of gravity lengthwise of the body, the muscular movements of adults are apt to be in a lateral rather than a longitudinal direction, so that the center of gravity is changed across the body. Accordingly the knife edges are placed on one side of the bed and spiral springs on the other when used for adults, rather than at the foot or head as when used with the crib or cage for infants or animals.

Certain details of the crib suspension have already been given in figure 2, but the exact connection between the crib and the tambour is shown in figure 5. One end of the crib, *L*, rests on a knife edge, *O*, while the other is supported by the spiral spring, *M*. A tube pneumograph, *N*, has its lower end attached to the crib, the upper end being fastened to a stout support soldered to the wall of the respiration chamber. The changes in tension of the air in the pneumograph are transmitted through the tube to a tambour, *P*, whose pointer traces the record upon the kymograph drum. A glass tee, *T*, with rubber tube and pinchcock, serves to equalize the tension in the tambour if there should be any permanent contraction or distention of the pneumograph.

The careful and frequent testing of both the pneumograph and the tambour for tightness is of practical importance. The pneumograph being inside the respiration chamber, and connected by a rubber tube to the outside, would obviously furnish a path for leakage of air out of the chamber, provided a leak in both the pneumograph and tambour should occur. Tests are readily made by immersing them in water and employing slight pressure with the mouth on the connecting rubber tube. The pneumograph is of the type regularly furnished by the Harvard Apparatus Company, but for use in the infant chamber it is somewhat shortened. The tambours, which are likewise supplied by the Harvard Apparatus Company, are covered with very delicate tambour rubber, which is liable to deterioration and should thus be frequently renewed and tested.

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[1] Benedict and Talbot, Am. Journ. Diseases of Children, 1912, 4, p. 129.

[2] After the observations reported in this publication had been completed, information was received from Dr. Paul Roth, of Battle Creek, Michigan, that in recording the body movements of men or women lying on beds, he had replaced the pneumograph with a small Politzer bulb, so adjusted as to be somewhat compressed by the bed frame. The bulb was connected to the tambour and kymograph. Preliminary tests made in the Nutrition Laboratory with the Politzer bulb arrangement have shown that the results of the variation in pressure on the Politzer bulb by variation in muscular activity are most satisfactory, not only with adults but also with small animals—a fact of special interest in connection with the research on infants. Two serious objections to the pneumograph, *i. e.*, the danger of leaks through the rubber and the difficulty of renewing the rubber, are thus obviated by the use of this bulb. A flexible rubber bulb of small size is best used.

A major change in position of the body of infants during the respiration experiment is not ordinarily to be expected. With animals there may be a change in the center of gravity of the body from one part of the cage to the other, and consequently a distension or shortening of the pneumograph with a corresponding increased or decreased tension on the tambour. Under these conditions it has been found advantageous to place in the rubber tube leading from the respiration chamber to the tambour a glass tee tube, with a short rubber tube and pinchcock on the open end. When the animal or infant has permanently or temporarily settled down in a new position and the tambour shows a distension or contraction, by opening the tee tube the normal pressure can again be secured and the curves will proceed at the normal level.

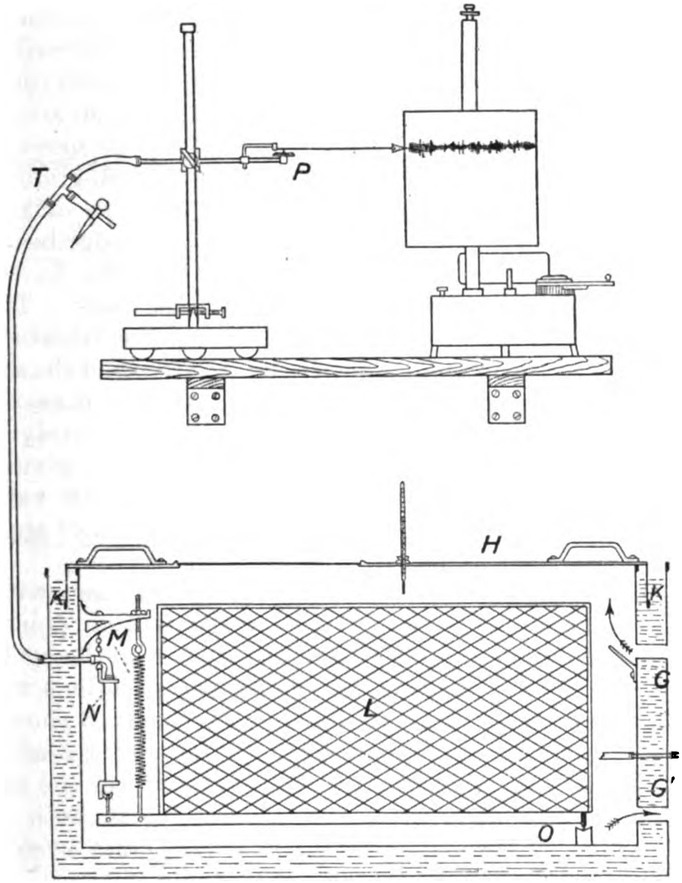


FIG. 5. Method of obtaining graphic record of muscular activity.

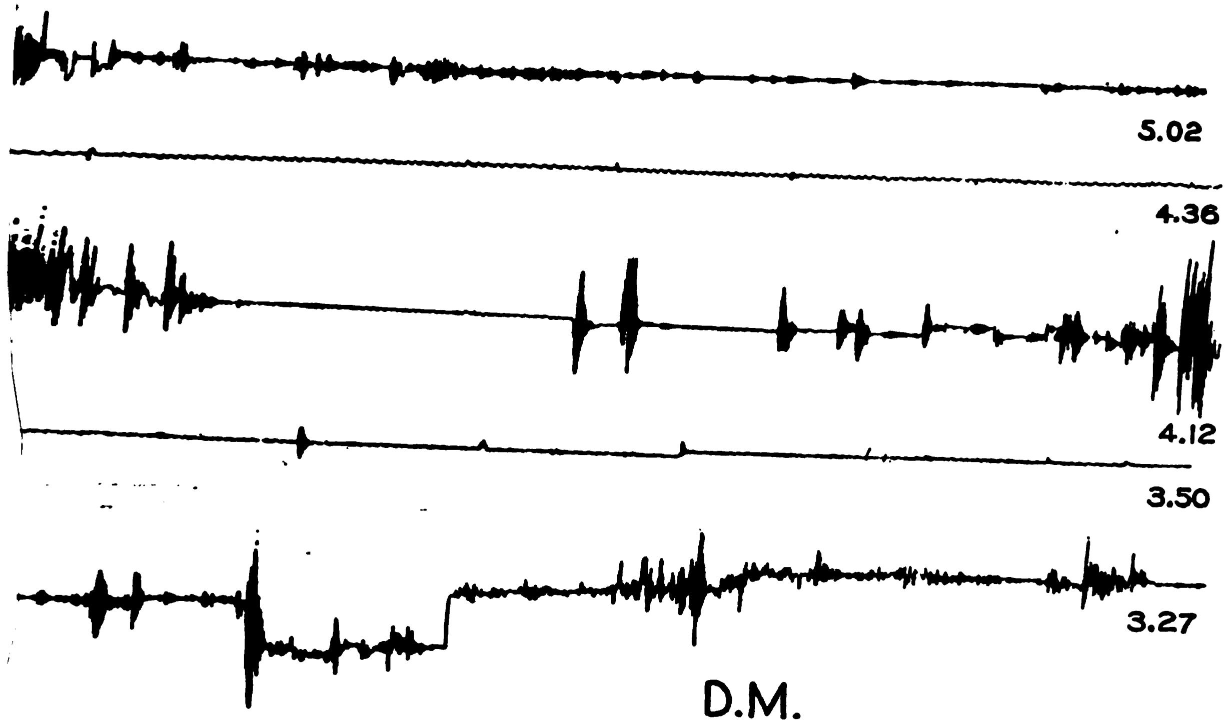
L, crib; *O*, knife-edge support; *M*, spiral spring; *N*, pneumograph; *P*, tambour; *T*, tee for equalizing tension; *H*, cover of apparatus; *K*, water bath; *G*, ingoing air-pipe; *G'*, outgoing air-pipe.

For the graphic record we have used extensively the simple Porter kymograph manufactured by the Harvard Apparatus Company, the most advantageous speed of rotation corresponding to one complete revolution of the drum in about 30 minutes.

It has been found desirable to precede the experiment with a test of the sensitivity of the apparatus for giving a good graphic record of the movements of the crib to make sure that the tambour rubber is intact and that there is a reasonably constant tension upon the tambour. For this purpose a weight is placed in the center of the crib approximately equivalent to the weight of the infant upon whom the observations are to be made. The tambour and pneumograph are then connected as usual and the kymograph set in motion, the speed being the same as that used in the experiment following. A 50-gram weight is next dropped from a definite height (21 cm.) so as to strike the crib a blow at a certain distance (32 cm.) from the knife-edge bearing upon which the crib rests. This imparts a slight impulse to the whole suspended system and a series of vibrations takes place. The amplitude of the vibrations as well as the number of the vibrations which continue after the first impulse indicate the sensitivity of the apparatus. This test is of great significance, accompanying as it does the kymograph record for each experiment and proving positively that the recording apparatus is in excellent condition. It also gives a rough estimate of the degree of muscular activity and the true value of the magnitude of the excursions of the pointer as the result of any restlessness on the part of the infant.

The tambour was usually adjusted in the observations with infants so that the distance between the end of the writing point and the center of the tambour rubber was 190 mm. and from the center of the tambour to the fulcrum 25 mm.; all of the magnifications were therefore on the same basis. The curves may be made to show motions that would otherwise be imperceptible to the eye by altering the magnitude of the multiplication and the sensitivity of the apparatus. For example, it has frequently been observed with both dogs and infants that when the animal or the infant is very quiet, even the slight change in the center of gravity produced by the respiratory movement has been sufficient to give a clear and regular record of the respiration-rate. Ordinarily such a degree of sensitivity is not at all necessary and is not regularly employed.

A typical kymograph curve, which was obtained with D. M. on March 26, 1913, is given in figure 6. This also shows a record of the sensitivity test which preceded the experimental periods. The vibrations of the crib after the weight had fallen are shown by typical curves which gradually decrease; the small disturbances of the line following, also resulting in curves, are due to the lifting of the weight. After the first test, the speed of the kymograph was increased and three tests were made at the higher rate of speed.



D.M.
MARCH 26,1913

The apparatus was so sensitive that even the slight movements due to respiration are clearly indicated, especially in the quiet period between $4^h\ 12^m$ p. m. and $4^h\ 45^m$ p. m. It will be seen by this curve that there were several major changes in the position of the infant's body which resulted in a total displacement of the level of the curve. Shortly afterward, air was released through the tee tube and the pointer was brought back to the original level. In any attempt to quantify the values of the different periods, these displacements of the curve due to major movements should be taken into consideration. A movement may not be sufficiently great to produce a considerable amplitude of the pointer and yet be produced by a shifting of the whole body, thus establishing a new, permanent center of gravity of the system. Obviously, in this case, a greater displacement could reasonably be supposed to have taken place than when the line returned to the same level.

It should be stated that the ocular method of observation of infants or animals during respiration experiments is most illusive and unsatisfactory. We have repeatedly seen experimental periods when a careful observer, even though watching the infant continuously, was unable to record a perceptible movement other than those of respiration, and yet the suspended crib, pneumograph, and tambour have recorded distinct and persistent muscular tremors, accompanied in all cases by an increasing pulse-rate and increased metabolism as measured by the oxygen consumption and the carbon-dioxide production. While, therefore, careful ocular observations, such as were made in the earlier experimenting at Wesleyan University in Middletown, Connecticut, are of great value in interpreting the gross metabolism, for extremely accurate observations the graphic method alone insures scientifically exact results. It is furthermore obvious that the sensitivity of the graphic method makes the continuous attention of an observer unnecessary, as the record of body movement is directly written without bringing the personal equation in any way into play.

WARD CRIB RECORDER.

The relationship observed between the graphic tracings of the muscular activity and the katabolism indicated the possible value of recording the activity of the infant throughout the day when it was not inside the respiration chamber. Accordingly, to assist in settling some complicated problems of nutrition, a special apparatus was devised and set up in the children's ward of the hospital in order to obtain a continuous graphic record of the muscular activity of the infant.

This apparatus, which was designated the "ward crib recorder," consisted of a small crib, one end of which rested on two hardened steel points and the other was suspended by a strong spiral spring. The movements of the crib due to the activity of the infant were graphically recorded by means of a pneumograph, tambour, and kymograph as used for the same purpose with the respiration apparatus (see figure 7).

For these 24-hour observations, the kymograph was set at a very much slower speed than in the short-period observations with the respiration apparatus to avoid the necessity of changing the kymograph frequently. The curves were therefore not so sharply defined as those secured when the infant was in the respiration chamber. Numerous curves were obtained with the ward crib recorder during the winter of 1913. The kymograph was adjusted by the nurses in charge, oftentimes during the night, so that certain irregularities in the time record are to be expected. When the infant was removed from the crib for bathing, nursing, or any other cause, the kymograph was of course stopped and a break in the record occurred. Such records as these, which were frequently obtained with infants who were supposed to be lying quietly in the crib throughout the night, are particularly helpful in estimating the needs for energy.

More recently another form of this recorder has been devised and successfully used. In this later apparatus the adjustment of the crib by means of the spiral spring remains the same. Instead of using the pneumograph and rubber tambour, however, the measurements and manipulation are simplified by substituting an ordinary mechanical counter. This consists of a small revolution counter, such as a Veeder counter, to the axle of which is attached a thin aluminium wheel 119 mm. in diameter, with a milled edge. A lever and spring pawl are attached to this toothed wheel in such a way that each upward movement of the crib causes the wheel to move slightly in the direction of the hands of a clock. As the crib returns to its original position, any back movement of the wheel is prevented by a second pawl fastened to the base of the recording device, but the spring pawl which engages in the teeth of the wheel slides back to its original position without material resistance. Since every upward movement of the crib produces a rotary motion of the wheel, it will be seen that the total movement for any period can be obtained from the number of revolutions of the wheel as recorded by the counter. The wheel is divided into 10 equal divisions and provided with a pointer, so that the readings may be obtained in hundredths of a revolution if desired. The details of the later device are shown in figure 8.

Two curves obtained with this form of the ward crib recorder are given in figure 9, one of these being for a very restless infant, J. P., November 14–15, 1913, and the other for one much less restless, M. A., November 17–18, 1913. With the restless infant, the toothed wheel made 18.4 complete revolutions during the period from 6 p. m. to 7 a. m. In the curve obtained with the less restless infant, the wheel made 5.2 complete revolutions in approximately the same time, *i. e.*, from 5 p. m. to 7 a. m.

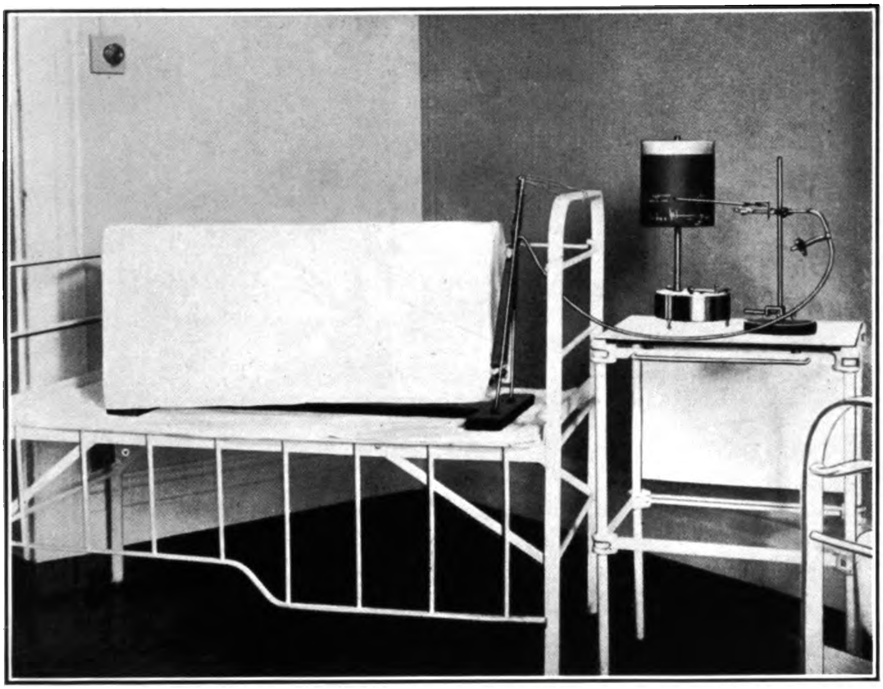


Fig. 7. Ward crib recorder.

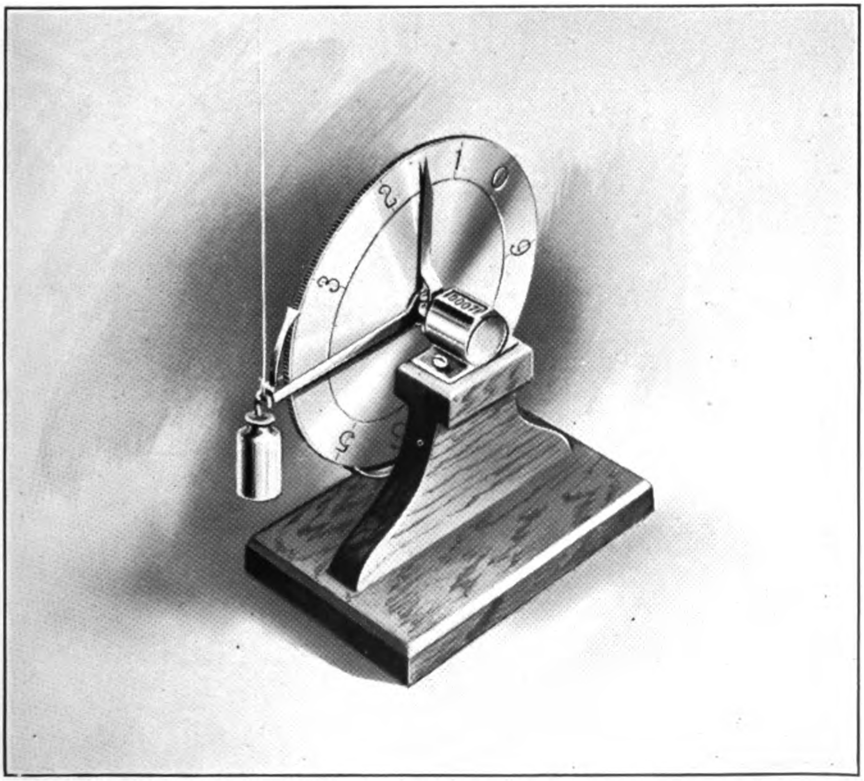


Fig. 8. Revolution counter used in later form of the ward crib recorder.

As yet no attempt has been made to measure the amount of increase in metabolism incidental to one complete revolution of the wheel, and it is a question whether quantitative values can be obtained with this device, especially for the comparison of results with different infants. But this method, which is inexpensive and simple, gives a general index of the degree of restlessness or muscular repose of infants, which should prove of value for ward use. This has already been shown in our more recent observations.

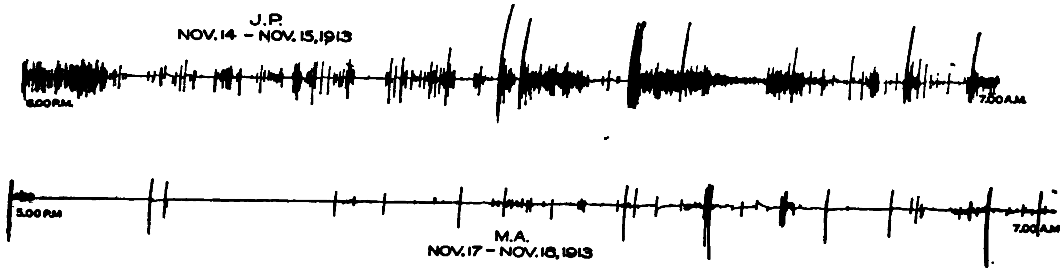


FIG. 9. Typical kymograph curves obtained with the ward crib recorder.

METHOD OF RECORDING THE PULSE-RATE.

Previous experiments with adults in the Nutrition Laboratory, in which the large respiration chambers were used, showed a striking relationship between the pulse-rate and the metabolism. Attempts were accordingly made to secure accurate pulse records in our observations with infants. For this purpose we attached the bell of a small Bowles stethoscope to the infant over the apex beat of the heart by means of strips of adhesive plaster. A rubber tube connecting with the bell led to a pipe in the wall of the chamber, a piece of rubber tubing and the earpieces being attached to the outer end of the tube. Even with a total length of some 2 or 3 meters from the bell to the earpieces, it was possible to count the pulse-rate of the weakest infant.

Since here again there is a direct connection between the inside of the chamber and the outside air, it is of the highest importance that the stethoscope and the rubber tube leading from it be tested for tightness. For this test, the stethoscope bell is immersed in water, and a slight pressure is put upon the diaphragm by blowing through the rubber tube. If it is not found absolutely tight, a thin coating of vaseline on the edge of the diaphragm usually insures a complete closure.

The importance of these pulse observations is so strongly impressed upon us that a special assistant is at present detailed in all of the experiments with infants for the sole purpose of recording the pulse-rate. The major muscular movements of the infant and any abdominal or chest sounds, such as grunting, sneezing, coughing, etc., may readily be heard through the stethoscope and are likewise regularly recorded upon the protocol sheet. It is also perfectly feasible to secure the respiration-rate in this way from time to time.

We are far from satisfied with this as a permanent method for securing a record of the pulse-rate, and it is our hope, in connection with the hospital or with the laboratory, to secure records either with the string galvanometer or with the Bock-Thoma oscillograph. It is clear that the records of the pulse-rate should be more objective than they can be even with a specially detailed assistant. During the experimental period, it is necessary to have the room absolutely quiet, and hence the assistant is not distracted by extraneous sounds. We regret, however, that a better method was not at the time practicable for recording a factor which is of such great significance in determining the general tonus of the body and therefore the basal metabolism.

GENERAL TECHNIQUE OF RESPIRATION EXPERIMENTS WITH INFANTS.

Previous to an observation, the length of the baby was measured by placing it upon a board with a head-board at right angles and a sliding foot-board. Subsequent to May 1, 1913, the infant was measured while flat on his back. Measurements were likewise taken of the circumference of the head above the ears, the chest over the nipples, and the abdomen over the umbilicus, as well as the greatest circumference of the thighs and the calves. The baby was also weighed naked. The rectal temperature was taken and recorded and the baby was given its food, except in certain instances when boiled water sweetened with saccharine was substituted. The infant was then immediately taken to the room in which the respiration chamber was placed.

Preliminary to the respiration experiment, the kymograph was wound, the wet bulb of the psychrometer thoroughly moistened with distilled water, the tambour tested under water to make sure that there was no defect in the rubber, and the pneumograph likewise tested for tightness. A sensitivity test of the apparatus was then made as previously described. In the bottom of the crib a small mattress or folded blanket was laid. The stethoscope was next properly adjusted by means of small strips of adhesive plaster and as soon as the infant was placed in the crib, the stethoscope tube was connected with the copper pipe in the wall leading to the earpieces outside. If the crib did not swing freely, the tension of the spring could readily be adjusted by raising or lowering a screw. In most instances, after placing the infant in the crib, it was found advantageous to pin the blanket in which it was wrapped at both the top and the bottom in the same manner that infants are wrapped when they are put to bed. The cover of the apparatus was then put on, the thermometer inserted in the top, the window covered with a black cloth, the ventilating current set in motion, and the time recorded.

The usual preliminary period sometimes lasted a considerable length of time, for it is obviously unwise to begin the first period of observation until the infant has been quiet for at least 15 minutes. The temperature of the water in the water jacket around the chamber was recorded and, if necessary, controlled by cooling during the period until the air inside the chamber, as recorded by the thermometer in the cover and by the thermometer in the outgoing air, had a temperature not far from 20° C. During this preliminary period, the air-current passed through one of the two sets of purifiers, the other set having previously been weighed and connected into position ready for use. Just prior to the end of the period, air was allowed to escape through a pet-cock in the system until the bell of the spirometer was about 30 mm. above the lowest point; the spirometer was then about half filled with oxygen, thus avoiding any possibility of there being a deficiency in the oxygen content of the air. While the rate of ventilation should be approximately constant, *i. e.*, about 35 liters a minute, it is practically impossible to regulate this unless a very constant electrical current is available. With the Crowell blower, as here used, about 270 revolutions a minute gives a suitable ventilation.

When the infant was perfectly quiet and the preliminary period was nearing the end, records were made of the readings of the wet- and dry-bulb thermometers, the thermometer in the top of the chamber, and the thermometer showing the room temperature. Air was then released from the system through the pet-cock until the spirometer pointer read about 30 mm. Inasmuch as there is a slight tension due to the uncompensated spirometer bell, the counterweight of the spirometer was taken in the hand and the bell gradually raised until the delicate petroleum manometer read zero. While the valves were turned to deflect the air-current from one set of air-purifiers to the other, the manometer was held at zero and the readings of the spirometer level taken immediately before and afterward. The beginning of the new period was marked on the kymograph record by the assistant, who then recorded the barometer reading and the temperature of the barometer. The readings on the oxygen meter having previously been taken or the oxygen cylinder carefully weighed, about one-half liter of oxygen was introduced or even more if the infant was very large or restless. This of course raised the spirometer bell. By determining the time in which the infant utilizes the half liter of oxygen, the oxygen supply can be regulated with considerable exactness, so that the spirometer reading will be nearly the same at the beginning and end of each period.

The length of a period of observation depends altogether upon the muscular repose of the infant, as only quiet periods, accompanied by a low pulse-rate, are of value. With a small, quiet infant, the periods may vary in length from 20 to 30 minutes, but with a large infant they may be as short as 15 minutes. About a minute and a half before the close of the period, the dry- and wet-bulb thermometers were again read, also the thermometer in the cover of the chamber, and the temperature of the room was recorded. The manometer was then adjusted to zero, the spirometer read, and the valves turned, thus deflecting the air through the original set of absorbers, which in the interim had been weighed and again connected. In the middle of the period, a test for possible unabsorbed carbon dioxide was made by deflecting a small part of the air-current for a few moments through a solution of barium hydroxide in a small flask, returning the air to the system again to insure no loss of air from the chamber.

Throughout the entire period of observation, the pulse-rate was recorded every two minutes by a nurse, who made this her sole duty. Likewise other body movements distinguishable by means of the stethoscope, such as coughing, crying, or a deep breath, were noted and an occasional record made of the respiration-rate, which was counted directly from the stethoscope.

Occasionally the observations had to be interrupted because a change in position of the baby displaced the stethoscope and the pulse-rate could no longer be counted. Under such conditions, it was necessary to remove the cover of the chamber and reapply the adhesive plaster. The stethoscope caused the baby no discomfort at any time. The ward records were consulted to determine the normal or minimum normal pulse-rate and when the record reached this point and the kymograph showed that the infant was quiet, a period was started. At first the infant was observed through the window in the cover of the apparatus to see whether or not he was quiet, but in many instances it was found that infants which appeared absolutely quiet to the eye showed slight movements on the kymograph and the pulse-rate remained high. The visual estimation was therefore discontinued as being too inaccurate and unreliable a record of the degree of quiet.

The conduct of such an observation as has been outlined is not unlike the actual technique involved in a short-period alcohol check test, although the results of the short experimental periods with an infant are by no means as satisfactory. The temperature distribution throughout the chamber is more uneven in observations with infants; furthermore, the slightest movement of the infant may so disturb the temperature equilibrium that at the end of the period the temperature will be somewhat different from that at the beginning. Such changes, of course, affect the determination of the oxygen; as a result, the respiratory quotients for successive periods do not often agree. It is perfectly feasible, however, to determine the respiratory quotient during the entire period that the infant is inside the respiration chamber, independent of whether the subject is quiet or restless; as so determined, the respiratory quotient is an accurate indication of the character of the combustion. On the other hand, the determinations of the carbon dioxide for each individual period are extremely exact. It is possible, therefore, to utilize the carbon-dioxide measurements as an index of the total katabolism for each individual period and the respiratory quotient for the whole sojourn inside the chamber as an index of the character of the combustion. It is thus perfectly logical to compute the indirect calorimetry from the measurements of the carbon dioxide and the calorific value of carbon dioxide for the particular respiratory quotient determined at the time.

This is the exact reverse of the method employed by Zuntz, who measures the oxygen consumption with great accuracy and computes the heat-output by indirect calorimetry, using the calorific value of oxygen with the various respiratory quotients. Theoretically either method gives reliable results and is without criticism. On the other hand, in experiments made with the respiration chamber, a rapid change in the value of the respiratory quotient is always possible. This is particularly true after feeding, since there may be a considerable rise in the respiratory quotient immediately after the food is taken, followed by a relatively rapid fall, thus materially affecting the indirect determination of the heat-output. Strictly speaking, therefore, the respiratory quotient should be determined for each individual period. As a matter of fact, in observations made a considerable time after the food had been taken, the respiratory quotient would remain relatively constant throughout the whole period of an hour or an hour and a half. In most of our observations the measurements of oxygen did not begin until some time after food was taken, and the preliminary period is not considered in our discussion of the respiratory quotient. While a gradual falling of the quotient would be expected as the time increased after food was taken, we have every reason to believe that, with the conditions obtaining in our observations, the actual fall in the quotient was very slight and could but rarely, if at all, affect the calculation of the indirect calorimetry. In this series of observations we have computed the indirect calorimetry from the direct measurements of the carbon dioxide, using the calorific values of carbon dioxide[1] for the respiratory quotients obtained during the experimental period.

The fact should again be emphasized here that tests for tightness and efficiency preceded every individual observation and check tests for determining the respiratory quotient with alcohol were made once a week.

The later method for determining the absolute amount of alcohol burned and the respiratory quotients for short periods approximating the periods of observation with infants was not perfected until the fall of 1913; nevertheless we feel confident that the number of control tests made with the older method in connection with these researches is fully justified in order to secure absolute accuracy in this, the first extensive use of the apparatus for studying infant metabolism.

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[1] See table 15, p. 29.

Publications of the Nutrition Laboratory.

Publications will be sent post-paid at the prices indicated. Orders should be accompanied by a remittance payable to the Carnegie Institution of Washington, Washington, D. C.

No. 42. Atwater, W. O., and F. G. Benedict. *A Respiration Calorimeter with Appliances for the Direct Determination of Oxygen.* Octavo, 193 pages, 49 figures. Published 1905. Price $1.25.

No. 77. Benedict, F. G. *The Influence of Inanition on Metabolism.* Octavo, vii+542 pages, 2 text figures. Published 1907. Price $2.75.

No. 123. Benedict, Francis G., and T. M. Carpenter. *Respiration Calorimeters for Studying the Respiratory Exchange and Energy Transformations of Man.* Octavo, vii+102 pages, 32 figures. Published 1910. Price $0.75.

No. 126. Benedict, Francis G., and T. M. Carpenter. *The Metabolism and Energy Transformations of Healthy Man during Rest.* Octavo, viii+255 pages. Published 1910. Price $1.75.

No. 136. Benedict, Francis G., and Elliott P. Joslin. *Metabolism in Diabetes Mellitus.* Octavo, vi+234 pages, 2 plates. Published 1910. Price $2.00.

No. 155. Benedict, Francis G., and Edgar P. Slack. *A Comparative Study of Temperature Fluctuations in Different Parts of the Human Body.* Octavo, v+73 pages, 38 figures. Published 1911. Price $0.50.

No. 166. Benedict, Francis G. *The Composition of the Atmosphere with Special Reference to its Oxygen Content.* Octavo, 115 pages, 1 plate, 1 text figure. Published 1912. Price $2.00.

No. 167. Benedict, Francis G., and Walter G. Cady. *A Bicycle Ergometer with an Electric Brake.* Octavo, 44 pages, 16 text figures. Published 1912. Price $0.50.

No. 176. Benedict, Francis G., and Elliott P. Joslin. *A Study of Metabolism in Severe Diabetes.* Octavo, 136 pp., 1 text cut. Published 1912. Price $1.25.

No. 187. Benedict, Francis G., and E. P. Cathcart. *Muscular Work: A Metabolic Study with Special Reference to the Efficiency of the Human Body as a Machine.* Octavo, 176 pages, 1 plate, 10 text figures. Published 1913. Price $2.50.

No. 201. Benedict, Francis G., and Fritz B. Talbot. *The Gaseous Metabolism of Infants with Special Reference to its Relation to Pulse-rate and Muscular Activity.* Octavo, 168 pages, 65 figures. Published 1914. Price $1.50.

Other Publications of Allied Interest.

No. 84. Osborne, Thomas B. *The Proteins of the Wheat Kernel.* Octavo, 119 pages. Published 1907. Price $0.75.

No. 156. Osborne, Thomas B., and Lafayette B. Mendel. *Feeding Experiments with Isolated Food-Substances.* Octavo, 53 pages, text figures i–xxi. Published 1911. Price $0.50.

——— (Part II): Octavo, pages iii+55–138, text figures xxii–cxxix, 1 plate. Published 1911. Price $1.00.

No. 116. Reichert, Edward T., and Amos P. Brown. *The Differentiation and Specificity of Corresponding Proteins and other Vital Substances in Relation to Biological Classification and Organic Evolution: The Crystallography of Hemoglobins.* Quarto, xix+338 pages, 100 plates, 411 text figures. In cloth binding. Published 1909. Price $9.00.

No. 173. Reichert, Edward T. *The Differentiation and Specificity of Starches in Relation to Genera, Species, etc.: Stereochemistry Applied to Protoplasmic Processes and Products, and as a strictly Scientific Basis for the Classification of Plants and Animals.* Quarto, in two parts. Published 1913. Price $16.00.

Part I. The Starch-Substance and Starch-Grain. Pages i-xvii+1-342, 102 plates containing 612 photomicrographs, charts A-J.

Part II. The Differentiation and Specificity of Starches. Pages i-xvii+343-900 and 400 charts.

No. 201. **Benedict, Francis G., and Fritz B. Talbot.** *The Gaseous Metabolism of Infants with special reference to its relation to pulse-rate and muscular activity.* Octavo, 168 pages, 65 figures.

A complete historical review of all the literature on the gaseous exchange and calorimetry of infants is followed by a presentation of several important problems in this field. A respiration apparatus, measuring simultaneously carbon-dioxide production and oxygen consumption and provided with a sensitive arrangement for registering automatically and graphically the slightest body movement, was used to study 37 infants during approximately 800 periods of observation. Continuous records of the pulse-rate, and a graphic representation of the degree of muscular repose enabled many important correlations with the respiratory studies.

A series of 12-hour continuous pulse records, accompanied by ocular observations of the degree of repose, showed a sudden and considerable increase of the pulse-rate with crying or nursing and a rapid return to the low level with cessation of crying and feeding.

A comparison of the pulse-rate with the muscular activity as determined by the kymograph records of a swinging crib showed invariably a close agreement. The metabolism also increased or decreased as the pulse-rate and activity increased or decreased. Distinct evidence of an increased pulse-rate and metabolism independent of external activity was interpreted as being an indication of internal work and suggested the pulse-rate as an index of this internal work.

Particular stress was laid upon a comparative study of the basal metabolism of the infants, *i. e.*, the metabolism during complete muscular repose as shown by the kymograph records. Under these conditions, it was found that while, in general, the smaller infants had the smaller total metabolism, there were a sufficient number of striking exceptions to prevent the formulation of a definite law. Similarly, there was no uniformity in the metabolism per kilogram of body-weight, although with "normal" children, the plotted chart gave indications of an approximately regular line. As many of the infants were under weight, the total metabolism was compared with the normal weight for the age, also the expected weight computed from the birth-weight and normal growth thereafter, but no approach to uniformity or regularity was apparent.

A discussion of the supposed relationship between body-surface and metabolism and a critique of the methods used for measuring body-surface introduces the discussion of the values found with these infants. No relationship was found between the age of the infants and the heat produced per square meter of body-surface, nor could any relationship be noted between the heat-production per square meter of body-surface and the actual body-weight, the normal weight for the age, or the expected body-weight.

Evidence secured with normal and atrophic infants of different ages and weights is presented to show that the active mass of protoplasmic tissue determines the heat-production. This active mass of protoplasmic tissue may be stimulated to a greater or less cellular activity, the intensity of the stimulus being indicated by the pulse-rate.

Benedict, Francis G., et Fritz B. Talbot. *Le métabolisme respiratoire des nourissons: une étude ayant particulièrement trait à la fréquence cardiaque et à l'activité musculaire.* Carnegie Institution of Washington Publication No. 201, 1914. 168 pages, 65 figures.

Une revue bibliographique de tous les travaux sur l'échange gaseux et sur la calorimétrie infantile est suivie d'une présentation de plusieurs problèmes importants par rapport au métabolisme respiratoire. On employa un appareil à respiration, qui mesure à la fois la production d'acide carbonique et la consommation d'oxygène et qui a une disposition sensitive pour enregistrer automatiquement et graphiquement les mouvements les plus faibles du corps. Avec cet appareil on poursuivit des observations sur 37 nourrissons pendant à peu près 800 périodes. Des enregistrements continus de la fréquence cardiaque et un graphique du degré de repos musculaire permirent à faire beaucoup de rapports importants entre ces facteurs et le métabolisme respiratoire.

Une série d'enregistrements continus de la fréquence cardiaque, faits pendant 12 heures, et accompagnés des observations oculaires du degré de repos musculaire, montra une accélération brusque et grande du pouls quand l'enfant pleura ou prit de la nourriture, et un fléchissement rapid du rythme du pouls quand l'enfant cessa de s'agiter.

Une comparaison de la fréquence cardiaque avec l'activité musculaire, qui fut déterminée par les tracés kymographiques avec un berceau oscillant, montra presque toujours une concordance proche. Avec l'accélération ou le fléchissement du rythme des pulsations et avec l'accroissement ou la diminution de l'activité musculaire il y avait aussi une altération pareille dans le métabolisme. Une augmentation marqué du pouls et du métabolisme, qui ne fut pas occasionnée par l'activité externe, on expliqua comme une indication de travail interne, et la fréquence cardiaque servit d'un indice de ce travail interne.

On attacha en particulier de l'importance à une étude comparative du métabolisme "basal" des nourrissons; c'est-à-dire, du métabolisme pendant un repos musculaire parfait, comme montré par les tracés kymographiques. Dans ces conditions on trouva que, pendant que les nourrissons plus petits eurent en général un métabolisme total plus faible, il y avait assez d'exceptions frappantes pour empêcher la formation d'un loi exact. Aussi il n'y avait pas d'uniformité dans le métabolisme par kilogramme de poids du corps, quoique avec des nourissons "normaux" la courbe montrât une ligne assez regulière. Parce que beaucoup des nourissons eurent une infériorité de poids, on compara le métabolisme total et le poids normal, et aussi le poids attendu, calculé du poids de naissance et de l'accroissement normal, mais on n'y trouva pas d'uniformité ou de régularité.

Une discussion du rapport attendu entre la surface du corps et le métabolisme et une critique des méthodes employées pour la mensuration de la surface du corps mène à une discussion des valeurs obtenues sur ces enfants. On ne trouva pas de rapport entre l'âge de l'enfant et la production de chaleur par mètre carré de la surface du corps, ni de rapport entre la production de chaleur par mètre carré de la surface du corps et le poids réel, le poids normal ou le poids attendu.

De l'évidence obtenue sur des enfants normaux et atrophiques d'âges et de poids différents est donné pour montrer que la masse active de tissu protoplasmique détermine la production de chaleur. Cette masse active de tissu protoplasmique soit stimulée à une activité cellulaire plus ou moins grande, et l'intensité de ce stimulus soit indiqué par la fréquence cardiaque.

Toutes les publications de la "Carnegie Institution of Washington" sont déposées dans la plupart des grandes bibliothèques des villes et des universités du monde.

Benedict, Francis G., und Fritz B. Talbot. *Der Gasstoffwechsel bei Säuglingen, mit besonderer Rücksicht auf seine Beziehung zu der Pulsfrequenz und der Muskeltätigkeit.* Octav-Format. Carnegie Institution of Washington Publikation Nr. 201, 1914. 168 Seiten, 65 Abbildungen.

Es wird eine vollständige Literaturübersicht über den Gasaustausch und die Wärmemessung bei Säuglingen durch eine Darstellung mehrerer auf diesem Gebiete wichtigen Probleme gegeben. Mit einem Respirationsapparat, der zu gleicher Zeit die Bestimmung der Kohlendioxydabgabe und des Sauerstoffverbrauches gestattet, und der eine empfindliche Vorrichtung hat, welche automatisch und graphisch die geringsten Körperbewegungen zu registrieren erlaubt, wurden Versuche an 37 Säuglingen in etwa 800 Versuchsperioden ausgeführt. Fortlaufende Aufzeichnungen von Pulszahlen und eine graphische Darstellung des Grades der Muskelruhe ermöglichten die Feststellung vieler, wichtiger Beziehungen zwischen diesen Faktoren und dem respiratorischen Stoffwechsel.

Eine Reihe von 12-stündigen, ununterbrochenen Pulsaufzeichnungen, die von augenscheinlichen Beobachtungen des Ruhgrades begleitet wurden, zeigte eine plötzliche und beträchtliche Zunahme der Pulsfrequenz beim Schreien oder beim Stillen, und eine rasche Wiederkehr zu der niedrigen Pulszahl beim Aufhören des Schreiens und des Stillens.

Ein Vergleich zwischen Pulszahl und Muskeltätigkeit, welch letztere durch die Kymographaufzeichnungen der schwingenden Wiege gegeben war, zeigte eine vollständige Ubereinstimmung. Mit jeder Steigerung und jedem Abfall der Pulsfrequenz und Muskeltätigkeit ging eine Steigerung beziehungsweise eine Abnahme des Stoffwechsels einher. Eine deutliche Erhöhung von Pulszahl und Stoffwechsel, die nicht durch äussere Muskeltätigkeit hervorgerufen war, wurde erklärt als ein Zeichen innerer Arbeit; als ein Anzeichen dieser inneren Arbeit diente die Pulszahl.

Besonders wurde Gewicht auf eine Vergleichsstudie des Grundumsatzes von Säuglingen gelegt, das ist, des Umsatzes während vollkommener Muskelruhe, wie sie von den Kymographaufzeichnungen zu ersehen war. Unter Einhaltung dieser Bedingungen wurde gefunden, dass, während im allgemeinen die kleineren Kinder einen niedrigeren Gesamtstoffwechsel aufweisen, doch eine hinreichend genügende Anzahl von auffälligen Ausnahmen besteht, welche die Aufstellung eines Gesetzes hindert. In ähnlicher Weise konnte keine Ubereinstimmung im Stoffwechsel pro Kilogram Körpergewicht gefunden werden, obgleich, wie der Entwurf einer besonderen Karte zeigt, für "normale" Kinder eine annähernd gerade Linie erhalten wurde. Da viele von den Kindern untergewicht waren, so wurde der Gesamtstoffwechsel verglichen mit dem Normalgewicht für das betreffende Alter, ferner mit dem nach dem Geburtsgewicht und normalem Wachstum erwarteten und berechneten Gewichte. Es konnte aber keine Ubereinstimmung oder Regelmässigkeit ersehen werden.

Eine Diskussion über die vermutete Beziehung zwischen Körperoberfläche und Stoffwechsel und eine Kritik über die Methoden für Bestimmung der Körperoberfläche bildet die Einleitung zu der Besprechung der mit den verwendeten Kindern gefundenen Werte. Es konnte keine Beziehung zwischen dem Alter der Kinder und der Wärmeproduktion pro Quadratmeter Oberfläche gefunden werden, noch konnte irgend eine Beziehung zwischen Wärmeproduktion pro Quadratmeter Oberfläche und dem wirklichen Körpergewicht, dem Normal-Gewicht für das betreffende Alter, oder dem erwarteten Gewicht festgestellt werden.

Damit dürfte für normale, wie für atrophische Kinder verschiedenen Alters und Gewichtes der Beweis geliefert sein, dass die active Masse des protoplasmatischen Gewebes bestimmend für die Wärmeproduktion ist. Diese active Masse von protoplasmatischem Gewebe mag zu einer grösseren oder geringeren Zelltätigkeit angeregt werde; die Intensität des Reizes wird angezeigt durch die Pulszahl.

Alle Publikationen der "Carnegie Institution of Washington" sind den meisten grossen Stadt- und Universitätsbibliotheken der Welt dediziert.

PART II.

STATISTICS OF OBSERVATIONS.

SELECTION OF SUBJECTS.

The infants studied were all kept in the children's ward of the Massachusetts General Hospital and were selected for the most part from those coming to the Out-Patient Department; a few came directly from the Boston Lying-in Hospital. In many instances they were placed in the wards for the purpose of having their digestion studied; in a few cases they came because of some slight indigestion or because they were not gaining weight satisfactorily.

Each infant that enters the children's ward of the Massachusetts General Hospital has a complete physical examination, including an examination of the ear drums; careful notes are also made as to the general appearance, actions, and digestion. When the physical examination of the infants selected for observation was normal—in most instances the records were naturally of a negative nature, as for example "no enlargement of the peripheral lymph nodes"—and the infant led a regular and uneventful life, it was considered a normal infant. In some instances the subjects were below weight but appeared normal in other ways. In such cases, the fact is recorded in the statistics.

The infants were under the general care of one of us who saw them each day, but the immediate care was detailed to the house physician and excellent trained nurses. The routine throughout the day was regular. They were weighed naked at the same hour each day by the same nurse. The nurses also recorded carefully how much food was eaten; the percentages of the food components given and the number of calories in the food taken were roughly calculated for each day. Notes were kept as to the character of the dejections, and the pulse-rate and body-temperature were recorded twice a day. The clothing was the ordinary clothing used in hospitals for infants of their age; the beds were the usual hospital cribs. The house officer took careful histories of all the infants, his physical examination and bedside notes being verified by one of us. These records were made and the infant studied before any observations were made of the metabolism in order to control all factors so far as possible.

Infants who were quiet and comfortable were considered to be the most favorable subjects for observation, but we were frequently disappointed in the results, as many infants who were supposed to be absolutely quiet during the 24 hours did not prove to be so. This led us to install in the ward a crib so adjusted as to give kymographic records of the degree of activity or quiet, like those obtained with the respiration chamber.[1] The infant selected for observation was placed in this crib for 24 or 48 hours and a graphic record of his muscular activity secured for the whole period. In one instance an infant who was said to be the "quietest baby in the ward, hardly moving all day," gave a surprising record in that it showed that she actually moved a great deal and that there were only a few hours out of the whole 24-hour day in which she was truly quiet.

HOSPITAL RECORDS.

The routine histories, records of the physical examinations, notes regarding the urine, stools, blood, and temperature, the pulse and respiration charts, and detailed records of the food were kept for all of the infants. The Wassermann reaction and the von Pirquet skin tests were also made in many of the cases noted in the statistics. It does not seem desirable to publish the complete hospital record of each infant that came under observation, as such an amount of detail would make it impossible to find the essential points without too much labor. This is particularly true because most of the evidence is negative as to whether or not an infant is normal. One complete record of a typical case will therefore be given and only such information recorded for the other cases as has a bearing on the metabolism or is pathological in character.

TYPICAL RECORD.

Subject, F. B. Male; date of admission to hospital, April 22, 1913; age, 5½ months.

Preliminary diagnosis. Feeding.

Family history. Father and one other child living and well. Mother lame from an old infantile paralysis. She was operated on in the Massachusetts General Hospital a year ago for "intestinal obstruction" which came on when she was 2 months pregnant.

Past history. Full term, instrumental delivery. Birth-weight, 4.54 kg. Breast-fed, 6 days, then mother had blood poisoning and infant was weaned.

Present illness. From the age of 10 days until admission to the hospital, has had recurring boils on different parts of the body. Was fed for two months on modified milk and lactose and after that a proprietary food was substituted for lactose because he was not doing well. Is now getting 2.7 per cent of fat, 8 per cent of sugar (extra sugar in the proprietary food), 2.1 per cent of protein, 6 feedings of 5 ounces. Takes bottle well, does not vomit. Is very constipated in spite of magnesia and orange juice.

Physical examination. Fairly developed, poorly nourished. Bright and intelligent. Strong cry. Almost no subcutaneous fat. Muscles small but firm. Holds head up and sits up without support. Skin of trunk shows scars of old furuncles and on scalp are two which have almost healed. There is a fine papular eruption on back of neck and between shoulders. Head well shaped. Anterior fontanelle depressed and measures 2×2 cm. in diameter.

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[1] For description see p. 59.

Posterior fontanelle closed. Sutures closed. No craniotabes. Parietal bones not prominent. Eyes: No discharge; pupils equal and react to light; external ocular movements normal. Ears: No discharge; tympanic membranes normal. Nose: No discharge; alæ nasi do not move with respiration. Mouth: Mucus membrane, good color; no teeth; in center of hard palate is an oval ulcer about 1 cm. long in diameter, which is shallow and apparently filled with granulations; tonsils not prominent or reddened; pharynx normal. Glands: Axillary normal; epitrochlears normal; submaxillary, cervical, posterior auricular, occipital, inguinal, and femoral glands all enlarged and vary in size from a pea to a large bean; are hard and non-tender. Chest: Symmetrical; expansion equal; very slight rosary; no Harrison's groove. Heart: Apex impulse felt in fourth space, 4 cm. from midsternum; dulness corresponds; right border 1 cm. from midsternum; upper border at third rib; sounds regular and of good quality; no murmurs; pulmonic second louder than aortic second. Lungs: Normal resonance, fremitus, and breath sounds; no râles. Abdomen above level of thorax, soft, very tympanitic. Moderate diastasis of recti. No masses or tenderness. Liver dulness extends from fifth space to 1 cm. below costal margin, where smooth edge is felt. Smooth edge of spleen is felt 3 cm. below costal margin. Genitalia normal. Extremities normal. No paralysis, contractures, or edema. Epiphyses of long bones not enlarged. Reflexes: knee-jerks present and equal. No Kernig sign. No stiffness of neck or neck sign.

April 22. Blood: Hæmoglobin, 70 per cent (Talquist); white count, 10,000. Smear normal. Polynuclears, 32 per cent; small lymphocytes, 20 per cent; large lymphocytes, 47 per cent; endothelial cells, 1 per cent. Wassermann reaction suspicious.

April 23. Urine: Pale; clear; acid; albumin, slightest possible trace. No sugar. Urobilinogen absent. Sediment, a few round cells. Stool: Greenish brown; pasty; normal odor; acid to litmus paper; few soft curds, no tough curds; little finely divided mucus.

April 24. X-ray examination immediately after bismuth feeding, and every hour thereafter for several hours.

April 25. Von Pirquet skin tuberculin, negative 48 hours. Stool: Greenish yellow and black; crumbly; acid; no curds. Bismuth in large amount. Total fat in moderate excess.

April 26. X-ray examination as before.

April 27. Stool: Yellowish-white and black mixed (bismuth); acid; normal odor; few soft curds; total fat in moderate excess.

April 28. Stool: Soft yellow; acid; many small soft curds, few tough curds; no mucus; total fat in moderate excess. X-ray examination as before. Takes bottle well; gaining weight in spite of starvation.

May 2. Summary: Underfed; under-weight; bright, happy infant; very active; always hungry for bottle; takes it quickly; not quite satisfied. Discharged, relieved, Out-Patient Department. Diagnosis: Feeding; syphilis (?).

The chart for this infant during his stay in the hospital is given in figure 10. This shows curves for records of the body-temperature, the pulse-rate, the respiration-rate, the body-weight, and the calories per kilogram of body-weight contained in the food.

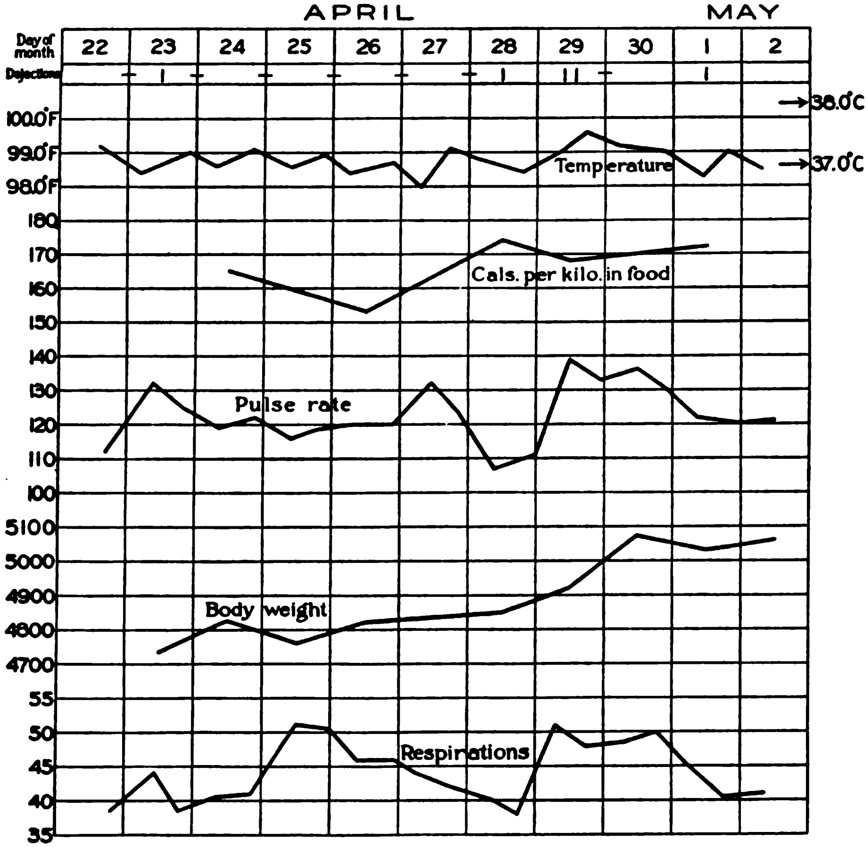

FIG. 10. Hospital chart for F. B.

One dejection in evening is indicated by —; one dejection during day by |; two dejections during day by | |. The records of the temperature were taken in the rectum.

This infant weighed about 2 kilograms less than the average weight for the age, and 3 kilograms less than he would have weighed had he developed in the normal manner. He was very much under weight, but gained consistently while in the hospital. He was considered to be in the convalescent stage of infantile atrophy. The daily records of the food, dejecta, and body-weight are given in table 21.

TABLE 21.—*Record of food, dejecta, and body-weight.*

Date.	Food.	Dejecta.	Body-weight.
1913.			*kilos.*
Apr. 22–23.	3 p. ct. fat; 6 p. ct. lactose; 1.4 p. ct. protein. 180 c.c. at 3, 6, and 10 p. m., 2^h30^m and 6 a. m.	2 greenish yellow and brown stools with many small soft curds and little mucus.	4.750
23–24.	3 p. ct. fat; 6 p. ct. lactose; 1.6 p. ct. protein. Extra sugar lactose. 180 c. c. at 9 and 12 a.m.; 210 c.c. at 2^h15^m p.m.; 195 c.c. at 6 and 10 p.m., 2 and 6 a.m. Total amount for day, 1350 c.c.	1 small constipated stool with fat curds.	4.825
24–25.	One feeding water, 90 c.c., whole milk, 120 c.c., bismuth, 30 gm. total (210 c.c.) at 9 a.m. Water, 210 c.c. at 2^h20^m p.m. Regular formula as on Apr. 23–24: 195 c.c. at 8 a.m., 90 c.c. at 10 a.m.; 195 c.c. at 2 and 6 p.m. Total for day, 1095 c.c.	1 large constipated stool with many soft curds. 1 large dark green dry stool. Acid.	4.750
25–26.	Regular formula: 195 c.c. at 9 and 12 a.m., 2^h15^m and 6 p.m.; 180 c.c. at 10 p.m.; 195 c.c. at 2 and 6 a.m. Total amount for day, 1350 c.c.	1 large soft dry yellowish green stool with many soft curds. Acid.	4.815
26–27.	One feeding whole milk, 120 c.c., bismuth, 30 gm., lime water, 24 c.c., water, 64 c.c. (total, 210 c.c.) at 9 a.m. Regular formula: 195 c.c. at 2^h15^m, 6 and 10 p.m., 2 and 6 a. m. Total for day, 975 c.c.	1 large green and white movement with many soft curds. Acid.	4.825
27–28.	Regular formula: 195 c.c. at 9 and 12 a.m.; 210 c.c. at 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1440 c.c.	1 large spongy yellowish green stool with many soft curds. Acid.	4.850
28–29.	Regular formula: 195 c. c. at 9 a.m. and 10 p.m.; 210 c.c. at 12 a.m., 3 and 6 p.m., 2 and 6 a.m. Total amount for day, 1440 c.c.; vomited about 30 c.c.	1 large soft formed yellow stool with many soft curds. Acid.	4.925
29–30.	1 feeding of whole milk, 120 c.c., bismuth, 30 gm., lime water, 60 c.c., water, 30 c.c. (total, 210 c.c.) at 9 a.m. Regular formula: 210 c.c. at 2^h15^m, 6 and 10 p.m., 2 and 6 a.m. Total amount for day, 1260 c.c.	2 large yellowish gray stools with many soft curds. 1 large yellow and very dark green stool with curds. Acid.	5.100
April 30 to May 1.	Regular formula: 210 c.c. at 9 and 12 a.m.; 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1470 c.c.	2 somewhat constipated yellow stools with specks of mucus. Acid.	5.025
May 1–2..	Regular formula: 210 c.c. at 9 and 12 a.m.; 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1470 c. c.	2 large yellow rather constipated stools with soft curds and little mucus. Acid.	5.050

SUMMARIZED HOSPITAL RECORDS FOR OTHER SUBJECTS.

Instead of giving the detailed records for each subject, as in the case of F. B., summaries of the hospital records are presented herewith which include all data of value in studying the results of the metabolism observations. These summaries are arranged in alphabetical order, and may thus be readily referred to.

Subject, M. A. Male; born February 11, 1913; birth-weight, 3.75 kilograms.

Previous to coming to the hospital, this infant had been breast-fed at intervals of 2 to 3 hours. Although never acutely ill, he had not gained weight as rapidly as the average infant, and had never been very strong. He usually passed 4 to 6 stools a day. An analysis of his mother's milk showed that it was very weak. He entered the hospital when 9 months old (November 3, 1913), with a severe secondary anæmia. His weight at that time was 5.70 kilograms. When the blood was examined, it was found that while the differential count of the white cells was normal, there was but 35 per cent of hæmoglobin (Talquist), 18,000 white blood corpuscles, and 2,712,000 red cells. The Wassermann reaction was negative. The physical examination showed that the infant was well developed and fairly nourished. The skin and mucous membrane were of a pale lemon color. The edge of the liver was felt 2 cm. below the edge of the ribs and the spleen was hard, extending down to the crest of the ileum. There was but a small amount of subcutaneous fat. The digestion was normal, but it was often necessary to feed him with a stomach tube. When discharged from the hospital on December 27, 1913, he weighed 5.60 kilograms. The case was diagnosed as splenic tumor with a severe grade of secondary anæmia. His weight on entering the hospital was 2.8 kilograms less than the average for an infant of his age.

Subject, J. B. Male; born October 19, 1912; birth-weight unknown.

This infant entered the skin ward of the Massachusetts General Hospital on February 21, 1913; his weight at that time was 3.06 kilograms. He was described as a poorly developed and nourished infant with an eruption typical of congenital syphilis. After inunctions of mercury were given him, the external evidence of syphilis disappeared. The physical examination was otherwise normal. During the 5 weeks this infant remained in the hospital he gained very little until the week preceding his discharge, when he gained approximately 0.5 kilogram, weighing when discharged 3.74 kilograms. His case was diagnosed as one of hereditary syphilis. He was very much underweight, weighing about 3 kilograms less than the average weight for his age. During the last week he was gaining weight and therefore may be considered as in the convalescent stage of infantile atrophy with syphilis.

Subject, L. B. Female; born at full term in September, 1912; birth-weight, 3.86 kilograms.

She was breast-fed for the first 2 months and subsequently fed on a mixture of milk, a proprietary food, and water. Her digestion was poor and she lost a little weight. She entered the hospital January 24, 1913, age 4 months, to have her metabolism determined. At this time she was a small, thin, but healthy-looking infant, with but little subcutaneous fat. She was not emaciated, however, and appeared well. She held up her head, but could not sit up without support. Her physical examination was normal. She was fed on modified milk in the usual proportions, her weight increasing from 3.89 kilograms to 4.07 kilograms, after which she ceased to gain. She was moderately under weight, as the average weight for an infant of 4 months is 6.25 kilograms. If she had grown in the usual way from birth, she would have weighed about 0.5 kilogram more than the average weight for an infant of this age. The hospital diagnosis was "regulation of feeding."

Subject, L. R. B. Female; born June 24, 1913; birth-weight, 4.08 kilograms.

This infant had always been breast-fed and had gained in the usual manner. She entered the hospital when 4 months old (October 31, 1913), to have her metabolism determined, and for weaning, as the mother was obliged to work. The physical examination showed that she was a well-developed, well-rounded infant, with the normal musculature and subcutaneous fat. The organs were all normal. On November 1 and November 3, modified milk was given her containing about 88 calories per kilogram of body-weight. On November 5, she was given milk containing 103 calories per kilogram of body-weight. The temperature was normal. Her weight was 6 kg; the average weight for an infant of her age is 6.25 kg.; she was therefore a perfectly normal infant.

Subject, A. C. Female; born February 2, 1913; birth-weight, 3.09 kilograms.

Her history was unimportant, and her physical examination normal. When she entered the hospital March 19, 1913, at the age of 6½ weeks, she was a strong, well-developed, and well-nourished infant. During her stay in the hospital she was fed with modified milk of the ordinary proportions and showed no signs of indigestion other than the occasional spitting up of small amounts of food. Her diet contained about 100 calories per kilogram of body-weight; with this diet her weight decreased in one week from 3.02 kilograms to 2.92 kilograms. Her temperature was normal except for two instances when it rose for no cause that could be discovered. She was to all appearances a normal infant. She weighed 0.4 kilogram less than the average weight for the age, but since she weighed 0.3 kilogram less than the average at birth this may be deducted from the average weight to show her expected weight for the age.

Subject, M. C. Female; born August 31, 1913; birth-weight, 4.09 kilograms.

She was breast-fed for a month and a half after birth and was then given modified milk; she had always been well. When 4 months old (January 1, 1914), she entered the hospital to have her metabolism determined; her weight at this time was 6 kilograms. The physical examination was normal and there was a normal amount of subcutaneous fat and muscle. Her temperature was normal throughout her stay. The average weight for an infant of this age is 6.25 kilograms; she was therefore approximately the weight of the average infant and on this basis may be considered a normal infant. As she weighed 0.68 kilogram more at birth than the average infant, she was approximately 0.75 kilogram below the weight she would have been had she gained in the usual manner.

Subject, A. D. Female; born December 28, 1912; birth-weight, 2.36 kilograms.

Previous to coming to the hospital she had always been fed on modified milk. She cried considerably and vomited immediately after almost every feeding. The milk formula had been changed, a month previous, to equal parts of cream, water, and lactose in amounts that gave her about 50 calories per kilogram of body-weight. She entered the hospital when 4 months old (April 26, 1913), with the provisional diagnosis of starvation. Her weight at that time was 2.55 kilograms, which was less than half of what she would have weighed had she gained in the normal manner, and 3.70 kilograms less than the average for an infant of that age. She was a poorly developed, poorly nourished, emaciated, and "dried up" infant, with a fairly strong cry and a feeble grasp. There was no subcutaneous fat and the muscles were small and weak. After coming to the hospital, she was fed on modified milk and gained rapidly in weight from May 1, when she weighed 2.60 kilograms, to June 5, when she weighed 3.70 kilograms. On May 18 it was noted that she was gaining very rapidly in weight and strength, and that her general appearance was improving. The digestion and temperature were normal except on the afternoon of May 24, when the temperature was 36.1° C. (97° F.). At the time of her discharge from the hospital, she weighed about 2 kilograms less than she would have if she had gained weight in the usual manner, and 3 kilograms less than the average weight of an infant of her age (5 months). She was therefore markedly under weight as a result of improper food and was on the border line of infantile atrophy. When her food was regulated, her digestion became good and she gained weight rapidly. She could be considered as being in the stage of convalescence.

Subject, M. D. Male; born February 23, 1913; birth-weight unknown.

He entered the hospital March 8, 1913, at the age of 2 weeks, to have his metabolism determined. Before coming to the hospital he had been fed partly on modified milk and partly at the breast. His history was negative. He was a well-developed, strong, well-nourished infant, who was normal in every way. While in the hospital, he was given modified milk. His digestion remained good but he did not gain in weight, presumably because he only received 80 to 90 calories per kilogram of body-weight. He weighed 4.05 kilograms, which was about the average weight for an infant of his age.

Subject, R. E. Male; born July 22, 1913; birth-weight, 2.27 kilograms.

His history was negative except for the fact that he had twice had jaundice. Previous to coming to the hospital, he had been fed on modified milk; his digestion was normal. He entered the hospital when 4½ months old (December 4, 1913), for the purpose of having his metabolism determined. The physical examination showed that he was well-developed and nourished, with firm musculature and considerable subcutaneous fat, though not an excessive amount. He was otherwise physically normal. The temperature varied between 36.4°C and 38.0° C. (97.6° F. and 100.4° F.). On entering the hospital, he weighed 5.1 kilograms; as the average weight for an infant of his age is 6.5 kilograms, he was 1.4 kilograms under weight, but since he weighed 1.1 kilograms less than the average at birth he was only 0.3 kilogram below his expected weight. He was otherwise a physically normal infant.

Subject, E. F. Male; born September 3, 1913; birth-weight, 4.22 kilograms.

He had always been breast-fed and thrived in every way. He was brought to the Out-Patient Department of the hospital, when 3 months old, for the purpose of having his metabolism determined. The physical examination showed that he was a well-developed, well-rounded infant, with a normal amount of subcutaneous fat. The average weight of an infant of his age (3 months) is 5.56 kilograms. At birth he was 0.8 kilogram heavier than the average infant, and with normal development he would be expected to weigh 6.36 kilograms at this age. He actually weighed 7.05 kilograms, or approximately 1.5 kilograms above the average weight for this age and 0.7 kilogram above what he would have weighed with normal development. He was therefore a perfectly normal infant.

Subject, E. G. Male; born January 23, 1913; birth-weight, 3.63 kilograms.

For the first 8 months after birth he was breast-fed and subsequently fed on modified milk. He had always thrived on this food. When 10 months old, he entered the hospital on November 25, 1913, to have his metabolism determined and for weaning. On physical examination he was found to be a normal well-developed and very well-nourished infant, with firm muscles and deep layers of subcutaneous fat. He had 4 teeth. His temperature was normal. His weight was 9.55 kilograms; the average weight for an infant of this age (10 months) is 8.75 kilograms; he was therefore 0.8 kilogram above the average weight and 0.6 kilogram above the expected weight. He may be characterized as a large, fat, normal infant.

Subject, E. K. Male; born at full term July 13, 1912; birth-weight unknown.

He was breast-fed for 2 months; subsequently he was given modified milk, and more recently was fed from the family table. He had never been well and when brought to the hospital on November 29, 1913, he was found to have broncho-pneumonia and rachitis. The metabolism was determined a week after he had recovered from the pneumonia. He was physically a fairly well-developed and nourished infant with a moderate amount of subcutaneous fat. When his metabolism was determined, his weight was only 8.03 kilograms, which is the average weight for an infant of 8 months, so that for an infant of 17 months he was very much under weight.

Subject, F. K. Male; born October 4, 1912; birth-weight, 3.54 kilograms.

For the first 3 months he was fed at the breast; he vomited considerably, was cross and fretful, and did not gain in weight. He was then weaned, and at first given modified milk, and later condensed milk, but without improvement, as he continued to vomit and to pass 6 to 8 loose green stools a day. He entered the hospital on May 1, 1913, at the age of 7 months. At that time he was a fairly developed and nourished infant, with a considerable amount of subcutaneous fat and firm muscles. The physical examination was normal. He was fed with modified milk having a caloric value of about 140 calories per kilogram of body-weight. His digestion and temperature were normal; he did not vomit during his stay in the hospital. His weight was 5.65 kilograms when he entered the hospital and 5.75 kilograms at the time of his discharge on May 11. He was about 1.5 kilograms lighter than the average for his age, but was otherwise perfectly normal.

Subject, A. L. Female; born at full term Mar. 2, 1913, birth-weight, 3.64 kg.

Previous to entering the hospital, she had been fed at the breast, but had been given supplementary feedings of a proprietary food and milk for a short time. She had always vomited more or less after the feedings and had recently been losing weight. Her weight on entering the hospital June 5, 1913, was 3.10 kilograms. The physical examination showed her to be a poorly developed, poorly nourished, and emaciated infant, with almost no subcutaneous fat. All of the peripheral lymph glands were slightly enlarged and there was a slight rosary. The other organs were normal. She was given a diet of modified milk during her stay of 6 weeks in the hospital; on her discharge she weighed 3.20 kilograms. The hospital diagnosis was "regulation of feeding." Since the average weight at 4 months is 6.25 kilograms and the expected weight would be essentially the same, she was about 3 kilograms under weight when discharged from the hospital.

Subject, E. L. Male; born January 19, 1913, of syphilitic parents; birth-weight unknown.

This infant was breast-fed for 1 month, then fed on modified milk, but was not satisfied with the food and did not gain in weight. He entered the hospital on May 15, 1913, at the age of 4 months. When examined he was found to be a rather small, fairly nourished infant, that lay quietly in the nurse's lap. He could not hold his head up. The skin was lax, with small amounts of subcutaneous fat. The physical examination was normal except that the edge of the spleen was felt just below the costal margin. The Wassermann test of the blood on May 20 was negative. He was fed with modified milk supplying approximately 120 calories per kilogram of body-weight. The temperature was normal. He had a chronic otitis media which required paracentesis five times while he was in the hospital. Any digestive disturbance during his stay was probably secondary to the infected ears. His weight on entering the hospital was 4.15 kilograms; on June 1, 4.48 kilograms; June 12, 4.48 kilograms; and on June 18, 4.68 kilograms. Since the average weight for 4 months is 6.25 kilograms, he was about 1.75 kilograms under weight.

Subject, R. L. Male; born at full term Aug. 14, 1912; birth-weight, 2.27 kg.

He entered the hospital on February 24, 1913, and an operation was performed for hare lip and cleft palate on March 12. The temperature became elevated after the operation and on the 16th a typical measles rash appeared. The temperature dropped to normal on March 22. He was discharged from the hospital on March 27. On April 5 he again entered the hospital with a high fever, a right upper lobar pneumonia, and infected ears. The temperature dropped to normal on April 19 and remained there until April 26, when he had pneumonia for a second time, which continued 8 days. On May 6 a double paracentesis was again necessary and from that time on there was no elevation of temperature. He was a large, well-developed, and well-nourished infant, with normal digestion. On April 15 he weighed 7.60 kilograms, while on May 16 he weighed 7.30 kilograms. At the age of 8 months, therefore, his weight was 0.47 kilogram less than the average for that age; on May 16, when he was 9 months old, he had lost weight and was about 1 kilogram below the average weight. On the other hand, as he was 1 kilogram or more under weight at birth, he was a little over the weight which would be expected with normal development.

Subject, D. M. Male; born April 24, 1912; birth-weight, 3.00 kilograms.

This infant was prematurely born at 8½ months. He was breast-fed for the first 5 weeks and subsequently fed on various modifications of milk, malted milk, and condensed milk. During November, 1912, he gained practically no weight and had frequent colds and pertussis. On February 24 he was brought to the Out-Patient Department of the hospital with a double otitis media. Later he had chicken pox. He entered the hospital when he was 11 months old (March 25, 1913). At that time he was found to be a fairly developed and nourished infant, with a small amount of subcutaneous fat and soft muscles. He was unable to sit up without support, the back showing a marked curve of weakness. The head was square, with a flat top and prominent parietal eminences. There was a slight rosary, but no enlargement of the epiphyses. The physical examination was otherwise normal. Despite the infected ear, the temperature did not rise higher than 37.78° C. (100° F.) during his stay in the hospital. He was given milk modified to suit his digestion, with a fuel value of about 140 calories per kilogram of body-weight. During the first few days he did not take the food from the bottle well, but after he had become accustomed to his surroundings, he gained in both weight and appearance, the gain in his general condition being much more than the weight indicated. When he entered the hospital, he weighed 5.20 kilograms; this weight fell to 5.10 kilograms on March 29, after which there was a gain until he was discharged in April, when he weighed 5.23 kilograms. He was about 4 kilograms below the average weight for his age, and about 3.6 kilograms below what he would have weighed had he gained in the usual manner.

Subject, F. M. Male; born September 13, 1912; birth-weight unknown.

His past history was unknown. When he entered the hospital on January 16, 1913, he had congenital syphilis, with a positive Wassermann reaction. The general physical examination was normal except that he was under weight, weighing only 4 kilograms, while the average weight for an infant of this age (4 months) is 6.25 kilograms. His temperature and digestion were normal.

Subject, J. M. Male; born July 28, 1912; birth-weight not known.

For the first two weeks after birth he was breast-fed; subsequently he was given whole milk diluted with water, which seemed to agree with him. Then he had diarrhea and was fed condensed milk. When 5 months old he was brought to the Out-Patient Department of the Massachusetts General Hospital, as he was constipated and not gaining. His weight on January 9 was 5.20 kilograms, or 1.60 kilograms below the average weight for this age (5 months). He was given milk suitably modified and gained weight slowly, his stools showing good digestion. About this time he had several colds. On March 6 he developed an acute otitis media which necessitated opening both ear drums; the discharge from the ears persisted up to the date of his entrance to the hospital ward on March 27, 1913 (at the age of 8 months). At this time he was found to be fairly well-developed and nourished, with a moderate amount of subcutaneous fat. The head was somewhat square and there was a slight rosary. There was a purulent discharge from both ears. All the peripheral glands, including the epitrochleas, were easily palpable, being the size of small shot. The physical examination was otherwise normal. Although the discharge from the ears continued, the ear infection caused no elevation of temperature after April 1 and no other symptoms. He was given milk modified to suit his digestion, with a fuel value of about 140 calories per kilogram of body-weight. His digestion was normal. At the time he entered the hospital, his weight was 5.50 kilograms; when he was discharged it was 5.63 kilograms, these weights being about 2.5 kilograms below the average for his age (8 months).

Subject, M. M. Female; born January 21, 1913; birth-weight, 3.18 kilograms.

She was fed on modified milk and did well until several days before coming to the hospital, when she began to vomit after feeding and to have diarrhea. Her mother gave her one-half ounce of castor oil and changed her diet to barley water. The infant entered the hospital on May 28, 1913. The physical examination showed her to be well-developed, strong, and bright, with a good amount of subcutaneous fat. The skin was a little loose, indicating a recent loss of flesh, but otherwise the examination was normal. The temperature, which was elevated on the day of admission, soon dropped to normal. She was given weak mixtures of modified milk which contained about half as much food as she required to gain weight. Her weight remained stationary at 5.35 kilograms. This was about 1.15 kilograms lighter than the average weight for an infant of her age (4½ months) and about 1 kilogram lighter than she would have been had she developed consistently from birth. The diagnosis was acute gastro-intestinal indigestion.

Subject, E. N. Female; born November 17, 1912; birth-weight not known.

Previous to coming to the hospital she had been fed on various proprietary foods, separately or in combination. She cried considerably and was hungry. She did not vomit and her stools were soft, green, and foul. When she entered the hospital on May 19, 1913, she was found to be a well-developed and fairly well-nourished infant, with a strong cry. The subcutaneous fat was in small amounts; the skin was lax and the muscles flabby, but the grasp was strong and she was able to hold her head up. The rest of the physical examination was normal. She cried very little while in the hospital, but "ate, laughed, and slept." Her weight on entering was 5.40 kilograms and on her discharge on June 2, 1913, it was 5.26 kilograms. She was 2 kilograms below the average weight for an infant of her age (6 months), but was otherwise normal in all respects. Her case was considered to be one requiring a regulation of feeding, her condition being due to improper feeding, with probably too much carbohydrate. No permanent injury had been done, as her digestion quickly became normal when she was given milk properly modified, with a fuel value of about 140 calories per kilogram of body-weight.

Subject, L. O. Male; born September 5, 1912; birth-weight, 3.75 kilograms.

This infant had always been fed with the bottle on mixtures of various proprietary foods, with little or no cow's milk. He lost weight on this diet and had never regained his birth-weight. When he entered the hospital at the age of 4½ months (January 29, 1913), the physical examination showed that he was a small, rather emaciated infant with a pinched face and practically no subcutaneous fat. The musculature was slightly flabby and he was unable to hold up his head. The cry was fairly strong and he seemed bright. The physical examination was otherwise normal. His weight on entering the hospital was 2.93 kilograms and it continued about the same until approximately February 15, when he began to gain slowly. On March 10 he weighed 3.32 kilograms. After that date his temperature was elevated and it was discovered on March 14 that he had measles. During the period when his metabolism was being determined, his temperature in the wards varied between 36.1° C. (97° F.) and 36.7° C. (98° F.), being subnormal in the morning and usually reaching 36.7° C. (98° F.) in the afternoon. On March 12, the temperature became elevated with the prodromal symptoms of measles.

He was a very much under-weight and under-nourished infant, with an indigestion which was presumably due in the first place to too much sugar in the diet and secondly to too much fat. There was no difficulty in digesting protein in relatively large amounts. His diet during his stay in the hospital was cow's milk modified to suit his digestion, and on this he gained slowly and consistently in weight until he had measles. The stools were at first loose, watery, and acid, but after the food was regulated they became firm, solid, and alkaline. He weighed less than his birth-weight when he should have weighed almost double his birth-weight; taking into account the subnormal temperature, general appearance, and history, he might be considered a case of infantile atrophy.

Subject, J. P. Male; born prematurely at 7 months April 11, 1913; birth-weight, 2.05 kilograms.

He was never breast-fed, but was given condensed milk, or modified milk with a proprietary food; he had never thrived on this diet. He entered the Floating Hospital August 14, 1913; his physical examination was negative at this time, except for emaciation. He gained in weight up to 4 kilograms, but then had indigestion, and was given a formula containing malt soup, which resulted in a gain in weight up to 4.54 kilograms. On September 12, 1913, he entered the Massachusetts General Hospital and was found on physical examination to be moderately emaciated, with an indigestion due to too large a proportion of fat in the diet. He was put on a diet of modified milk, regulated to his digestion, and on September 28 began to gain rapidly. On October 25, he weighed 5 kilograms and on November 8, 5.5 kilograms. He was happy and smiling, well covered with fat, and his physical examination was normal. He was, however, approximately 2 kilograms under weight, as the average weight for his age (7 months) is 7.7 kilograms. Since he weighed 1.35 kg. less than the average at birth, he would have weighed 6.4 kg. if he had gained normally. On this basis, he weighed 0.9 kg. less than he should have weighed.

Subject, W. P. Male; born August 23, 1912; birth-weight, 2.73 kilograms.

His history previous to his coming to the hospital was unimportant, save that his food contained practically no fat, he was very constipated, and not gaining in weight. On January 24, 1913 (age, 5 months), he entered the hospital ward to have his metabolism determined. At that time he was an undersized and rather poorly nourished infant, with but a small amount of subcutaneous fat. He noticed objects, and held up his head, but could not sit up without support. His physical examination was normal except that there was a slight rosary. While in the hospital he kicked and laughed a good part of the day while awake, slept 6 hours during the day and all night except when fed at 10 p. m., 2 a. m., and 6 a. m., and was considered a particularly happy infant. He made slow but consistent gains without symptoms. His food was modified milk and his digestion was normal. When he entered the hospital, his weight was 4.14 kilograms and on February 2 (9 days later), 4.39 kilograms. When discharged from the hospital, he was about 1 kilogram below the weight he would have been if he had doubled his birth-weight in 5 months and 2.5 kilograms below the average weight for a baby of his age.

Subject, D. Q. Male; born at full term on Aug. 2, 1913; birth-weight, 2.5 kg.

He was breast-fed for the first 2 months, and subsequently on modified milk. When on the latter food, he had diarrhea in December, but when the formula was modified the digestion became perfect. He entered the hospital on December 22, 1913, at the age of 4½ months, for the purpose of having his metabolism determined. He was then reported as gaining rapidly. He was well-developed and nourished, with firm muscles, and a well-developed layer of subcutaneous fat. Both the physical examination and the temperature were normal. He was under weight, as he weighed only 5.2 kilograms and the average weight for this age is 6.5 kilograms. His birth-weight was, however, 0.9 kilogram less than the average infant at birth and if he had gained normally he would have weighed approximately 5.6 kilograms. He was, therefore, 0.4 kilogram below what he should have weighed.

Subject, E. R. Male; born January 12, 1913; birth-weight, 2.95 kilograms.

His father was unknown; his mother was treated for syphilis by two injections of salvarsan during pregnancy. During the first seven weeks he was breast-fed; subsequently he was fed both breast and modified milk on which he did well. He entered the hospital April 11, 1913, to have his metabolism determined; at that time he was well-developed and well-nourished with a moderate amount of subcutaneous fat and strong muscles. The physical examination was normal except for an enlarged spleen which could be felt 3 cm. below the edge of the ribs; this was believed to indicate syphilis. His temperature was normal. At birth he weighed 0.45 kilogram less than the average infant; when he entered the hospital he weighed 4.50 kilograms or about 1 kilogram less than the average infant of the same age (3 months). His digestion was normal and except for the first few days, he gained weight consistently during his stay in the hospital, that is, after his food was strengthened from 100 to 120 calories per kilogram of body-weight.

Subject, K. R. Male; born December 6, 1912; birth-weight, 4.55 kilograms.

Previous to his coming to the hospital, he had always been fed on modified milk, but did not do well. He entered the hospital on April 2, 1913, at the age of 4 months. On physical examination he was found to be poorly developed, poorly nourished, and almost emaciated. He had a thin, pinched face, no subcutaneous fat, and the skin was rather loose. The muscles were small and fairly firm. He cried considerably and held his breath for periods as long as 45 seconds, during which he became distinctly blue, but there was no suggestion of a crow or of laryngismus stridulus. The physical examination was otherwise normal. The urine was also normal except that on one examination it showed a possible trace of albumen. This, however, was probably of no significance, as there were no other pathological signs. He was fed on a mixture of cow's milk, relatively low in fat, which gave him about 120 calories per kilogram of body-weight. During his stay in the ward his digestion was apparently normal. His temperature was normal or subnormal. He was an undersized infant, whose digestion had been upset by over-feeding with fat. When he entered the hospital, his weight was 3.07 kilograms, which was less than his birth-weight. If he had developed in the ordinary way, he would have weighed about twice as much, the average weight for an infant of his age being 6.25 kilograms. When discharged from the hospital, he weighed 3.19 kilograms. His case was considered to be one of infantile atrophy.

Subject, A. S. Male; born at full term Dec. 26, 1912; birth-weight, 3.75 kg.

His history was unimportant, as he had always been breast-fed. When he entered the hospital on March 26, 1913, he was well developed and well nourished, with a normal amount of subcutaneous fat and firm muscles. He appeared strong and bright and held his head up without support. The physical examination was normal. During his stay in the hospital he was fed both breast and modified milk; his digestion was normal. It was necessary to puncture his ear drums on March 29 to relieve an acute otitis media, after which the temperature, which had previously been moderately elevated, dropped to normal. His weight remained stationary in the week he was under observation. He was a normal breast-fed infant, weighing approximately 6 kg. or about 0.5 kg. above the average weight for his age (3 months).

Subject, E. S. Female; born of healthy parents on October 13, 1912 (presumably premature at about 7 months); birth-weight, 1.93 kilograms.

She was breast-fed for 3 months but did not gain. She was then put on a diet of malted milk and later on a proprietary food, both of these being mixed with milk. While she did not vomit, she spit up her food occasionally, and had two brown stools a day which irritated the buttocks. When she entered the hospital on March 19, 1913, she had not gained weight recently. On physical examination she was found to be a poorly developed, thin infant, with an anxious expression. There was no subcutaneous fat, and the muscles were flabby. She appeared quiet but bright, and had a strong cry. The skin showed a dull redness, with macular papular eruption on the chin, joints, and buttocks. The physical examination was otherwise normal. She was fed on milk modified to her digestion, with a fuel value of about 140 calories per kilogram of body-weight; while under observation, her digestion was good. This infant was much under the average weight and also under the weight which she would have been had she gained consistently. With a history of prematurity and a birth-weight of 1.93 kilograms, it would be expected that at the age of 5 months (her age while in the hospital) she would weigh approximately 5.35 kilograms, whereas her average weight for this time was about 3 kilograms. The average weight for an infant of 5 months is 6.82 kilograms. She was, therefore, considerably under weight. Furthermore, the temperature during her entire stay was subnormal. She was accordingly considered to be a case of infantile atrophy.

Subject, E. H. S. Male; born at full term Aug. 28, 1913; birth-weight, 3.18 kg.

He had always been fed on modifications of cow's milk or on condensed milk, but did not thrive on any of the diets used. He had had symptoms of indigestion ever since birth and had lost weight, weighing when he entered the hospital on October 27, 1913, at the age of 2 months, only 2.4 kilograms. He was a poorly developed and nourished infant, with the expression of an old man. The face wrinkled when he cried, and the skin hung in folds on his arms and legs. The fontanelles and eyes were sunken; the skin was dry;

the hands and feet were cold. The physical examination was otherwise normal and the Wassermann reaction was negative. During a part of his stay in the hospital, it was impossible to give him the usual number of calories in his food, as, for instance, on November 24, when he received only 90 calories per kilogram of body-weight; the temperature at this time was subnormal, being 36.1° C. to 36.7° C. (97° F. to 98° F.). On November 13 and 21, when he received about 130 calories and 145 calories respectively, the temperature was normal. When he was discharged on December 27, 1913, he weighed 3.05 kilograms. His case was diagnosed as infantile atrophy. He weighed when 2 months old 0.8 kilogram less than at birth. His digestion was very weak.

Subject, G. S. Male; born December 1, 1912; birth-weight, 3.64 kilograms.

Since his birth he had been fed on various home modifications of milk, barley water, lime water, and milk sugar. He seemed hungry, cried considerably, and did not gain in weight. When he entered the hospital February 12, 1913, he was found on physical examination to be a well-developed but poorly nourished infant, with a small amount of subcutaneous fat. He appeared bright and active and had a strong cry. His weight was the same as at birth, whereas at his age (2½ months) it should have been 1.5 kilograms more. He was given milk modified to his digestion, with a fuel value of about 100 calories per kilogram of body-weight. Digestion not remarkable. His temperature remained normal. He was considered to be a case of regulation of feeding.

Subject, J. S. Male; born December 28, 1912; birth-weight, 5 kilograms.

For the first 6 weeks he was breast-fed; subsequently he was given a modification of cow's milk, but vomited after each feeding, cried most of the time, and was very constipated and hungry. He entered the hospital on June 3, 1913, at the age of 5 months. On examination he was found to be a small, emaciated infant, with the facies of old age. There was no subcutaneous fat and the skin hung in folds. The muscles were strong but firm. There was a slight rosary, but the physical examination was otherwise normal. He was given modified milk, with a fuel value of approximately 120 to 140 calories per kilogram of body-weight. The temperature was normal during his stay in the hospital. He was an atrophic infant with no definite signs of indigestion. His weight on entering the hospital was 4.08 kilograms and on his discharge 4.53 kilograms. This was less than his birth-weight and only half what he should have weighed at his age.

Subject, P. S. Male; born December 23, 1912; birth-weight unknown.

He had never been a well infant. On September 20, 1913, he had acute bronchitis. He entered the hospital on November 19, 1913, and had bronchopneumonia on November 21. Later he had otitis media. In the week preceding the determination of his metabolism, his temperature had been normal and he had gained in weight, although previous to that time he had lost considerable weight. His digestion was also good, and his physical examination was normal. His weight on December 18 was 7 kilograms, this being about 2 kilograms under weight, as the average weight for an infant of his age (12 months) is 9.5 kilograms.

Subject, H. T. Male; born October 25, 1912; birth-weight unknown.

This infant was breast-fed from birth and had always been healthy. He was brought to the hospital for weaning and taken into the ward on April 15, 1913, to have his metabolism determined. The physical examination was normal, showing that he was a strong, well-developed and well-nourished infant, with a large amount of subcutaneous fat. During his stay in the hospital he received both breast milk and modified milk. His digestion and temperature were normal. He weighed about 2 kilograms more than the average infant of the same age (5½ months), his weight remaining stationary at 9.28 kilograms while he was in the hospital.

Subject, J. V. Female; born prematurely at 8 months on October 10, 1912, of a syphilitic mother; birth-weight, 1.45 kilograms.

She lost weight until at the end of the first week she weighed only 1.30 kilograms. For the first 4 weeks she was fed on human milk; she was then discharged from the Boston Lying-in Hospital to the Massachusetts General Hospital, which she entered on December 13, 1912. At this time she was a moderately nourished, poorly developed infant, about 45 cm. long. She cried lustily and took her food with a Breck feeder without help. A diagnosis of congenital syphilis was made by the skin department of the hospital before she entered the Children's Ward. From December 25 onward, she was given inunctions of mercury, one-half strength, until her discharge from the hospital.

On December 15, two days after her entrance, the temperature became elevated and remained so until the 20th, when it was found that she had an acute otitis media. After paracentesis, the temperature dropped to normal and remained there for several weeks. On March 11, the temperature again became elevated and 2 days later it was found that the infant had measles. The temperature remained elevated 7 days. She was allowed out of quarantine on March 27. On March 31 she again had acute otitis media, which was relieved by paracentesis. The ears continued to discharge until April 10; two days later paracentesis was once more necessary and there were symptoms of adenoid obstruction. On April 17, the adenoids were removed under ether, thus relieving the obstruction. After this the infant ate, acted, and looked better. On April 20 it was noted that there was marked craniotabes, a moderate rosary, a liver which could be felt 4 cm. below the edge of the ribs, and a spleen 3 cm. below the ribs. The ears stopped discharging shortly after the adenoids were removed and the general condition was much improved. On May 12, the record was made that she "laughed out loud."

She was fed on increasing strengths of modified milk. Her digestion was weak during most of her stay in the hospital. The weights recorded were as follows: October 10, 1912 (birth-weight), 1.45 kilograms; December 14, 1.84 kilograms; January 1, 1913, 1.84 kilograms; January 15, 1.92 kilograms; February 1, 2.05 kilograms; February 15, 2.22 kilograms; March 1, 2.50 kilograms; March 15, 2.70 kilograms; April 1, 3.10 kilograms; April 15, 3.00 kilograms, this being double her birth-weight; May 1, 3.10 kilograms; May 12, 3.33 kilograms. Although she doubled her birth-weight at 6 months, she weighed less than half the average weight of infants of the same age.

Subject, P. W. Male; born September 8, 1912; birth-weight unknown.

His family and past history were unimportant. He entered the surgical department of the hospital on March 26, 1913, because of acute retention of urine due to a horse hair tied tightly around the base of the penis. This was quickly relieved by removing the cause. His physical examination was normal. He was a healthy, well-developed infant, who acted normal in every way. During his stay the infant was given modified milk and digested it well. His food contained only about 85 calories per kilogram of body-weight, his weight remaining stationary at 7.10 kilograms. Since his birth-weight is unknown, it is impossible to calculate what his weight should have been for his age on that basis, but this weight is approximately the same as the average for his age. His temperature was normal and he could be considered a normal infant of average development.

CLINICAL STATUS OF INFANTS.

Table 22 summarizes the clinical status of each infant studied, and gives the age of the infant during the metabolism observations.

TABLE 22.—*Clinical status of infants studied.*

Name.	Age during metabolism observation.	Clinical status.
F. B.	5½ months.	Convalescent stage infantile atrophy.
M. A.	9 months.	Under weight, splenic tumor, with anemia.
J. B.	5 months.	Congenital syphilis, convalescent stage, infantile atrophy.
L. B.	4 months.	Under weight.
L. R. B.	4–4½ months.	Normal infant.
A. C.	1½ months.	Slightly under weight.
M. C.	4 months.	Normal infant or slightly under weight.
A. D.	4–5 months.	Convalescent stage, infantile atrophy.
M. D.	2–3 weeks.	Normal infant.
R. E.	4½ months.	Under weight or slightly under expected weight.
E. F.	8 months.	Normal infant.
E. G.	10 months.	Normal infant.
E. K.	17 months.	Much under weight; rachitis, recovering from broncho-pneumonia.
F. K.	7 months.	Under weight.
A. L.	3½–4 months.	Under weight.
E. L.	4 months.	Under weight, otitis media.
R. L.	6½–9 months.	Approximately normal; later, under weight.
D. M.	11 months.	Much under-weight, rachitis.
F. M.	4–5 months.	Under weight, congenital syphilis.
J. M.	8 months.	Under weight, otitis media, rachitis.
M. M.	4½ months.	Under weight following an acute indigestion.
E. N.	6½ months.	Under weight.
L. O.	5–6 months.	Infantile atrophy.
J. P.	6½–7 months.	Under weight, gaining weight rapidly.
W. P.	5–5½ months.	Under weight.
D. Q.	4½ months.	Under weight.
E. R.	3 months.	Under weight (slightly).
K. R.	4 months.	Infantile atrophy.
A. S.	3 months.	Normal infant, weighing more than the average.
E. S.	5 months.	Infantile atrophy.
E. H. S.	2½–4 months.	Infantile atrophy.
G. S.	2½ months.	Under weight.
J. S.	5–6 months.	Infantile atrophy ? (temperature not subnormal).
P. S.	12 months.	Under weight.
H. T.	5½ months.	Normal infant, weighing more than average.
J. V.	3½–9 months.	Prematurity; congenital syphilis; infantile atrophy in subnormal temperature, and convalescent stage.
P. W.	7 months.	Normal infant.

RESULTS OF OBSERVATIONS ON THE GASEOUS EXCHANGE.

With an investigation extending over so many months and dealing with so many subjects as were used in this research, it is obviously impracticable to present protocols for each observation. On the other hand, as the carbon-dioxide production, oxygen consumption, pulse-rate, and muscular activity were accurately recorded in each experimental period, it seemed desirable to present the data in permanent form. This is done in table 23.

Accordingly, the carbon-dioxide production per hour, respiratory quotient, average pulse-rate, and the estimated activity are given for all of the observations and one line of the table is assigned for each experimental period. The arrangement by subjects is arbitrarily alphabetical, the observations with each infant being recorded in chronological order. Additional information is given as to the sex, age, and body-weight without clothing for the infants included in the study. While the carbon-dioxide production has been calculated on an hour basis, the actual length of the periods is also given, and the carbon-dioxide production for the individual periods may be readily calculated. No period is included which was less than 10 minutes in length. The results for the preliminary period of nearly all of the observations are given, usually appearing in the first line of the data, but as these are not used either in securing the average minimum metabolism,[1] or in computing the respiratory quotient, the experimental periods are bracketed to indicate this. No time is given for the observations, as the experiments were almost without exception carried out in the afternoon. The relation between the times of the observation and of the last feeding is recorded in the footnotes of the table; when this is not indicated, the feeding was invariably within 3 hours of the time when the infant was placed in the apparatus. Usually the preliminary period ended about 1 to 1½ hours after feeding. A key to the designations of the relative activity is placed at the head of the table. A full explanation of this method of estimating the activity may be found on p. 136.

TABLE 23.—*Results of observations on the gaseous exchange of infants.*

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. A., male, 9 mos.*	*mins.*	*gm.*			
Nov. 12	5.70 kilos..........	20⅓	5.71	....	117	V
		30	4.66	0.81	103	III
		30	5.04		103	III
		30	4.64		101	III
		42	5.01		104	IV
Nov. 14	5.63 kilos.........	71	5.97	....	125	VI
		30	4.68	0.79	105	II
		30	4.96		101	III
		22	5.65		113	VI
Nov. 17	5.80 kilos.........	25⅓	6.45	....	118	IV
		30	5.90	0.88	114	III
		30	5.96		116	IV
		23	5.66		110	IV
		22	5.29		110	III

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. A.* (cont.).	*mins.*	*gm.*			
Nov. 17[2]	5.73 kilos..........	35	5.45	....	123	VI
		35	4.87	0.80	103	II
		30	5.00		108	III
Nov. 18[3]	5.50 kilos..........	26	5.28	....	125	VI
		29	4.86	0.78	116	V
		30	5.30		118	IV
		25	5.69		134	VI
Nov. 18[4]	5.48 kilos.........	17	4.73	....	117	IV
		27	4.64	0.73	110	III
		30	5.00		114	III
		34	5.49		118	V
	F. B., male, 5½ mos.					
Apr. 23	4.75 kilos..........	10	7.38	....	127	IV
		30	5.44	0.87	112	II
		20	7.68		122	III
		30	5.42		112	II
		30	5.74		117	II
		29	5.50		107	II
Apr 24[5]	4.83 kilos..........	11	7.47	....	123	IV
		28	5.19	0.85	112	II
		29	5.15		117	III
		22	4.80		107	I
		23	5.22		114	I
		30	6.74		138	VI
Apr. 25	4.75 kilos...........	14	6.69	....	118	III
		20	5.58	0.86	111	II
		30	6.14		116	III
		18	5.30		107	III
		20	6.27		113	IV
		25½	5.11		101	II
Apr. 29	5.15 kilos...........	14	5.91	....	126	II
		23	5.79	0.88	119	I
		25	6.07		121	III
		24	5.88		114	III
		22	6.41		116	IV
		25	5.38		108	II
	J. B., male, 5 mos.					
Mar. 15	3.23 kilos..........	11	3.71	....	109	II
		41	3.95	0.94	113	IV
		27	3.76		103	II
		21	2.94		94	II
		15	4.08	....	102 ?	III

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 6 hours previous to these observations.

[3] Last feeding was about 20 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4] Last feeding was about 25 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[5] Last feeding was about 7 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. B.* (cont.).	*mins.*	*gm.*			
Mar. 17	3.23 kilos..........	12	5.35	....	96	II
		30	3.88	0.96	97	II
		21	4.14		106	IV
		26½	3.35		87	I
		20½	4.10		...	IV
	L. B., female, 4 mos.					
Feb. 1	4.06 kilos..........	12	5.85	....	135	V
		30	3.80	0.84	127	II
		30	4.14		133	I
		30	3.84		123	I
		30	3.90		122	I
		30	3.84		120	III
Feb. 3	....	10	6.00	....	139	IV
		30	4.00	0.91	127	II
		37	5.04		133	V
		18	4.33		125	IV
Feb. 4	4.04 kilos...........	30	4.24	....	121	IV
		17	4.76	....	127	V
		17	5.96	....	130	VI
Feb. 5	4.01 kilos...........	13	4.94	....	135	V
		30	4.08	0.92	121	III
		27	5.40		138	V
		19	5.34		136	VI
		14	5.61	....	127	V
		30	4.22	0.95	119	II
		30	4.04		121	III
		30	4.12		117	III
	L. R. B., female, 4 mos.					
Nov. 1	6.08 kilos...........	17	6.28	....	...	V
		27	4.64	0.80	...	III
		55	6.08		...	VI
		30	4.30		...	III
Nov. 3	6.05 kilos...........	30	4.62	0.85	...	II
		50	6.14		...	VI
Nov. 3[2]	5.93 kilos...........	23	6.68	....	137	VI
		23	4.36	0.77	106	III
		26	4.18		113	IV
		30	4.20		107	I
Nov. 4[3]	5.95 kilos...........	29	4.12	0.73	102	II
		30	4.52		110	II
		29	4.14		103	III
Nov. 4[4]	5.95 kilos...........	51	5.96	....	...	VI
		29	4.39	0.74	...	II
		35	5.54		124	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 4½ hours before these observations, sterile water being given in place of food at the next time of feeding.

[3] Last feeding was about 19½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[4] Last feeding was about 24 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*L. R. B.* (cont.), *4½ mos.*	*mins.*	*gm.*			
Nov. 5	6.00 kilos...........	28	6.43	....	126	VI
		30	4.70	0.83	105	III
		22	5.73		119	V
		30	4.70		106	II
		22	4.96		110	III
	A. C., female, 1½ mos.					
Mar. 19	3.00 kilos...........	10	3.48	....	138	IV
		30	2.20	0.84	120	I
		27	2.49		129	III
		29½	2.24		119	II
		30½	2.81		132	IV
Mar. 20	3.02 kilos...........	26	3.35	....	142	III
		30	2.40	0.93	131	II
		24	2.53		128	II
		27½	2.23		120	II
Mar. 24	2.95 kilos...........	32	2.94	....	139	III
		30	2.48	0.88	131	I
		30	2.84		141	III
		27	2.64		132	II
		25	3.02		136	III
1914.	*M. C., female, 4 mos.*					
Jan. 1	6.05 kilos...........	16½	6.23	....	119	VI
		25	4.42	0.84	99	II
		26	4.78		109	II
		37	4.52		107	II
		20	6.09		124	VI
Jan. 2	6.20 kilos...........	29	5.54	....	121	V
		23	5.22	0.88	102	II
		23	4.67		102	III
		30	5.98		122	VI
Jan. 3	6.25 kilos...........	24½	6.56	....	124	VI
		26	4.82	0.85	99	II
		22	5.84		107	V
		31	5.13		103	II
Jan. 5	6.03 kilos...........	43½	6.30	....	136	VI
		25	4.75	0.90	121	IV
	A. D., female, 4 mos.					
Apr. 28	2.65 kilos...........	46	4.43	....	128	V
		84	3.94	0.83	126	V
May 8[2]	2.95 kilos...........	20	3.27	0.89	112	III
		23	3.34		121	III
		24	3.00		110	I
		22	2.75		106	II
		30	2.86		106	II
		20	2.76		99	II
		20	4.71		146	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 7 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*A. D.* (cont.), *4½ mos.*	*mins.*	*gm.*			
May 12	3.01 kilos...........	14	4.54	....	127	I
		30	4.20	0.90	131	III
		32	4.18		131	II
		30	3.56		116	I
		33	3.71		123	II
May 15[2]	3.20 kilos...........	21	5.14	....	143	V
		30	3.80	0.94	124	III
		29	3.37		111	II
		19	3.98		123	IV
		28	5.74		154	VI
May 19[3]	3.23 kilos...........	14	3.13	....	115	I
		30	3.10	0.77	120	II
		25	3.02		113	I
		31	3.12		117	III
		23	2.66		104	I
		30	3.74		128	V
	A. D. (cont.), *5 mos.*					
May 24	3.43 kilos...........	31	5.83	....	137	V
		24	4.28	0.92	118	III
		30	4.30		127	II
		26	3.60		113	I
		30	3.92		124	III
	M. D., male, 2 weeks.					
Mar. 8	4.08 kilos...........	19	3.95	....	150	IV
		30	3.14	0.86	136	IV
		30	4.64		152	V
Mar. 10	3.97 kilos...........	17	3.67	....	145	IV
		21	3.00	0.80	144	III
		30	2.92		140	III
		30	3.00		140	III
		30	2.86		135	II
		25	2.74		131	III
Mar. 11	4.00 kilos...........	30	2.90	0.84	133	IV
		30	2.66		129	III
		30	2.88		123	III
		30	2.60		121	II
		20	3.99		137	IV
	M. D. (cont.), *3 weeks.*					
Mar. 14	4.00 kilos...........	22	3.08	0.83	128	IV
		37	3.47		132	V
		24	4.15		149	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 3 hours before these observations, sterile water being given in place of food at the time of feeding preceding these observations.

[3] Last feeding was about 21 hours previous to these observations. Sterile water was substituted at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*R. E., male, 4½ mos.*	*mins.*	*gm.*			
Dec. 4	5.10 kilos...........	41	6.64	....	129	VI
		24	4.55	0.83	114	IV
		23	4.70		118	II
		21	6.14		137	V
Dec. 4[2]	5.03 kilos...........	46½	5.89	....	141	VI
		22	4.45	0.82	121	III
		32	4.22		115	III
		29	4.04		117	IV
Dec. 5[3]	5.00 kilos...........	16½	4.22	....	106	III
		30	3.92	0.74	109	II
		24	4.08		115	II
		30	3.90		114	II
		30	5.18		137	V
Dec. 5[4]	4.95 kilos...........	15	4.36	....	119	III
		29	3.68	0.72	119	III
		111	6.46		141	VI
Dec. 9	5.03 kilos...........	19	5.94	....	133	V
		31	4.63	0.74	114	III
		33	4.36		115	II
		31	5.54		131	VI
Dec. 12	5.00 kilos...........	73	7.61	....	140	VI
		26	4.32	0.99	113	IV
	E. F., male, 3 mos.					
Dec. 2	7.05 kilos...........	18½	8.98	....	146	VI
		31	4.20	0.81	109	II
		26	8.45		140	VI
Dec. 3	7.08 kilos...........	32½	9.32	....	140	VI
		25	4.70	0.89	113	III
		24	8.78		137	VI
	E. G., male, 10 mos.					
Nov. 26	9.43 kilos...........	15½	6.77	....	112	II
		31	6.70	0.72	119	V
		23	6.63		115	IV
		23	5.97		111	II
		30	6.78		120	II
		30	8.44		133	VI
Nov. 27	9.45 kilos...........	47½	7.71	....	116	VI
		32	6.36	0.76	109	II
		19½	6.74		115	IV

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 6 hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[3] Last feeding was about 18½ hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

[4] Last feeding was about 24 hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*E. G.* (cont.)	*mins.*	*gm.*			
Nov. 27[2]	9.45 kilos...........	18	6.77	....	105	I
		30	5.76	0.71	98	I
		28	6.11		104	II
		30	5.94		100	IV
Nov. 28[3]	9.13 kilos...........	17½	6.58	....	111	III
		25	6.70	0.72	115	V
		26	6.81		113	IV
		30	5.94		108	II
		25	7.87		137	VI
Nov. 28[4]	9.20 kilos...........	34	7.13	....	115	V
		31	6.46	0.70	112	IV
		32	6.11		110	III
		21	6.03		112	IV
		26	7.75		126	VI
	E. K., male, 17 mos.					
Dec. 16	8.03 kilos...........	72	7.84	....	116	V
		29	6.70	0.80	105	II
		29	6.83		105	II
	F. K., male, 7 mos.					
May 2	5.68 kilos...........	22	7.45	....	138	VI
		16	6.34	0.84	121	IV
		22	5.40		109	I
		30	5.96		116	III
		30	7.58		141	V
May 3[5]	5.68 kilos...........	13	6.69	....	129	V
		20	5.13	0.78	109	I
		27	5.62		122	II
		20	8.94		168	VI
May 5[6]	5.70 kilos...........	14	7.24	....	128	V
		23	5.30	0.84	108	III
		32	5.64		118	III
		24	5.30		111	II
		20	6.78		136	V
May 6	5.70 kilos...........	19	7.39	....	136	VI
		20	5.73	0.89	112	II
		20	5.82		112	II
		23	6.37		119	IV
		21	5.71		109	III
		30	5.98		119	III

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 5½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[3] Last feeding was about 19½ hours previous to these observations. Sterile water was substituted in place of food at subsequent times of feeding.

[4] Last feeding was about 24½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[5] Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[6] Last feeding was about 6 hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*F. K.* (cont.)	*mins.*	*gm.*			
May 7[2]	5.75 kilos...........	14	7.11	....	133	V
		23	5.03	0.78	103	II
		19	5.49		113	III
		32	8.06		160	VI
May 9[3]	5.72 kilos...........	18	7.60	....	138	VI
		18	5.30	0.77	113	III
		21	4.89		105	II
		20	7.20		159	VI
	A. L., female, 3½ mos.					
June 14	3.10 kilos...........	21	5.11	....	136?	VI
June 16	3.10 kilos...........	60	4.82	....	127	VI
		15	4.28	0.89	110	I
		23	4.77		138	V
June 20	3.14 kilos...........	82	6.18	....	145	VI
		32	6.69	....	157	VI
June 23[4]	3.13 kilos...........	20	5.37	....	142	VI
		44	6.52	....	161	VI
June 24[4]	3.20 kilos...........	14	4.11	....	119	IV
		21	3.00	0.88	112	II
		24	4.45		133	VI
	A. L. (cont.), *4 mos.*					
June 28	3.15 kilos...........	42	4.73	....	118	V
		17	3.42	0.81	101	II
		22	5.21		125	VI
		36	5.17	....	137	VI
	E. L., male, 4 mos.					
May 17	4.15 kilos..........	12	5.75	....	136	III
		23	4.28	0.83	126	II
		24	4.98		134	III
		30	4.32		127	I
		30	4.90		130	III
		29	4.39		132	III
May 20	4.25 kilos...........	25	6.07	....	149	IV
		49	6.39	0.92	158	VI
May 21[5]	4.30 kilos...........	13	4.48	....	128	I
		47	6.87	0.93	159	VI
	R. L., male, 6½ mos.					
Mar. 3	8.10 kilos..........	30	6.20	0.87	112	II
		30	6.54		117	II
		30	6.84		121	III
		30	6.66		126	II

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 9 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[3] Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4] On June 23 and 24 the last feeding was about 3 hours previous to the observations, sterile water being given in place of food at the next time of feeding.

[5] Last feeding was about 3 hours previous to these observations. Sterile water being given in the place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*R. L.* (cont.)	*mins.*	*gm.*			
Mar. 4	8.09 kilos	22	9.38	....	138	V
		30	7.62	0.87	129	IV
		30	6.84		128	III
		30	8.06		137	V
		30	7.20		130	III
Mar. 7	7.97 kilos...........	61	8.28	....	141	VI
	R. L. (cont.), *8½ mos.*					
Apr. 26	7.68 kilos	25	8.18	....	138	III
		20	7.65	0.88	137	II
		30	7.54		137	II
		26	7.75		149	IV
May 9	7.25 kilos	20	8.46	....	125	V
		21	6.89	0.89	119	IV
May 10	7.18 kilos...........	32	7.31	....	115	V
		26	5.91	0.81	105	II
May 13	7.25 kilos...........	40	8.30	....	131	VI
May 14[2]	7.25 kilos...........	15	7.96	....	119	IV
		20	6.78	0.86	110	II
		22	6.74		114	III
		22	7.06		107	IV
		30	6.90		107	III
		18	7.50		114	IV
May 16[3]	7.30 kilos...........	23	6.99	....	125	V
		20	5.64	0.74	110	II
		30	6.40		114	III
		26	5.93		110	III
		29	6.14		113	III
		28	5.66		111	IV
	D. M., male, 11 mos.					
Mar. 26	5.21 kilos..........	32	7.13	....	151	VI
		46	6.53	0.89	138	V
		22	5.43		123	III
		30	7.66		147	VI
Mar. 27	5.28 kilos...........	55	9.39	....	176	VI
Mar. 31	5.15 kilos...........	15	8.48	....	161	V
		30	6.26	0.84	140	III
		30	6.04		132	III
		15	5.48		121	III
		26	5.77		127	IV
		30	5.24		115	II
		17	5.75		120	III

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

[3] Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*F. M., male, 4 mos.*	*mins.*	*gm.*			
Jan. 22	3.57 kilos...........	36	7.37	....	140	VI
		26	4.75	0.89	127	IV
		30	5.06		127	V
		49	4.27		118	III
		30	4.48		116	II
Jan. 23	3.52 kilos...........	77	7.27	....	152	VI
		30	4.02	0.86	119	II
		30	4.46		123	II
		30	4.00		116	I
	F. M. (cont.), *5 mos.*					
Feb. 20	3.86 kilos...........	57	7.53	....	147	VI
		27	7.40	....	141	VI
		30	4.86	0.83	119	III
		30	4.70		118	II
	J. M., male, 8 mos.					
Apr. 2	5.54 kilos.........	30	6.82	0.87	121	II
		23	7.25		122	II
		24	7.63		125	IV
		20	7.02		119	III
		13	8.35		132	IV
		25	6.94		115	II
Apr. 4	5.72 kilos...........	10	8.70	....	132	V
		25	7.08	0.89	112	I
		30	7.40		113	III
		23	7.38		111	IV
		18	6.70		102	II
		30	7.34		112	IV
		16	6.41		97	I
		20	8.49		115	VI
	M. M., female, 4 mos.					
June 2	5.43 kilos...........	20	5.91	....	113	V
		23	4.38	....	95	I
		22	4.58	....	101	III
		24	6.18	....	118	VI
June 3[2]	5.46 kilos...........	27	4.00	0.87	96	II
		25	4.34		99	II
		30	4.28		96	II
June 5[3]	5.55 kilos...........	28	4.84	....	107	V
		30	3.66	0.77	93	I
		21	4.06		96	III
		27	3.80		90	II
		25	4.85		113	VI

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[3] Last feeding was about 9 hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. M.* (cont.).	*mins.*	*gm.*			
June 7[2]	5.40 kilos...........	16	4.95	....	111	VI
		28	3.62	0.74	98	I
		19	4.52		104	IV
		30	3.64		96	II
		30	3.64		99	II
		20	5.46		127	VI
	E. N., female, 6 mos.					
May 21	5.40 kilos...........	52	9.10	....	150	VI
		19	7.36	0.90	134	VI
		20	4.98		109	I
		20	5.52		121	II
May 22[3]	5.40 kilos...........	23	5.48	0.92	119	II
		23	5.40		117	I
		20	5.49		112	I
		32	5.42		115	I
		20	6.99		139	V
May 23[4]	5.41 kilos...........	72	7.83	....	152	VI
		19	4.52	0.80	109	I
		22	5.07		116	I
		20	4.56		106	I
		20	5.10		124	I
May 26[2]	5.25 kilos...........	15	6.16	....	126	IV
		20	4.50	0.78	104	I
		30	4.82		112	I
		30	4.84		113	I
		31	5.81		140	V
May 28[4]	5.38 kilos...........	20	5.55	....	118	III
		25	4.92	0.86	106	I
		21	5.09		111	I
		22	5.10		103	I
		25	5.21		110	II
		23	4.62		105	I
May 29[5]	5.45 kilos...........	14	5.79	....	124	III
		27	5.31	0.88	116	II
		30	5.54		116	II
		27	5.82		115	III
		20	5.40		110	III
	E. N. (cont.) *6½ mos.*					
May 31[3]	5.48 kilos...........	18	6.97	....	117	III
		25	5.33	0.90	104	I
		24	5.65		114	II
		23	5.19		105	I
		20	6.78		130	V

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 21 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[3] Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[4] Last feeding was about 9 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[5] Last feeding was about 4 hours before these observations, sterile water being given in place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*L. O., male, 5 mos.*	*mins.*	*gm.*			
Feb. 10	2.99 kilos...........	32	3.60	....	106	III
		30	3.88	....	105	IV
		30	3.98	....	110	IV
		30	3.92	....	109	IV
Feb. 12	2.98 kilos...........	30	3.82	....	110	III
		19	3.98	....	102	III
		30	4.14	....	109	IV
		30	4.20	....	113	IV
	L. O. (cont.), *5½ mos.*					
Feb. 18	3.05 kilos...........	30	4.00	0.88	119	III
		30	3.90		114	III
		30	4.08		121	IV
		30	3.86		115	IV
Feb. 24	3.18 kilos...........	10	4.80	....	110	V
		20	4.35	0.87	113	IV
		22	3.63		99	II
		30	4.12		111	III
		30	3.86		103	III
		30	3.94		103	II
Feb. 25	3.15 kilos...........	12	5.85	....	116	V
		30	4.28	0.90[2]	111	IV
		30	4.22		107	II
		30	3.84		100	III
		30	4.04		104	V
		30	4.18		111	IV
Feb. 28	3.12 kilos...........	30	4.06	0.95	112	III
		30	4.06		103	II
		30	3.90		102	II
		25	4.20		125	VI
		30	4.30		119	IV
Mar. 1	3.15 kilos...........	11	4.42	....	111	IV
		30	4.00	0.97	105	III
		30	4.06		107	II
		30	3.58		93	I
		30	4.12		107	V
		30	4.32		105	IV
	L. O. (cont.), *6 mos.*					
Mar. 7	3.31 kilos...........	10	5.52	....	121	VI
		30	4.04	0.96	109	III
		22	4.25		115	V
Mar. 12	3.31 kilos...........	30	4.30	0.89	123	II
		20	4.74		129	III
		30	4.52		130	IV
		23	4.62		122	III
		30	5.14		138	V

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Determined for the time included in the first two and the last two periods.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. P., male, 6½ mos.*	*mins.*	*gm.*			
Oct. 31	5.40 kilos...........	40	7.71	....	140	VI
		30	5.84	0.87	...	II
		30	6.40		...	III
		29	5.52		...	III
		19	6.41		113	IV
Nov. 6	5.60 kilos...........	25	6.72	0.89	114	IV
		48	6.26		112	IV
		33	6.45		110	V
Nov. 7	5.65 kilos...........	13	7.11	....	121	IV
		30	6.48	0.91	102	I
		30	6.14		103	II
		35	6.29		107	IV
		30	5.54		106	II
Nov. 10	5.55 kilos...........	16½	6.91	....	115	V
		30	6.40	0.89	105	IV
		30	6.06		104	IV
		30	6.18		107	III
		30	6.16		106	IV
Nov. 10[2]	5.40 kilos...........	88½	7.05	....	126	VI
		30	5.00	0.86	102	III
		30	5.52		108	III
Nov. 11[3]	5.35 kilos...........	20	5.82	....	119	V
		30	5.06	0.79	106	II
		28	5.36		110	IV
		20	5.55		108	IV
	J. P. (cont.), *7 mos.*					
Nov. 11[4]	5.30 kilos...........	19½	5.63	....	129	V
		35	5.34	0.73	112	V
		32	6.06		117	VI
		23	4.96		107	IV
	W. P., male, 5 mos.					
Jan. 27	4.31 kilos...........	15	6.92	....	143	VI
		30	6.26	0.88	134	V
		30	5.16		120	IV
		30	6.12		130	V
Jan. 29	4.26 kilos...........	15	7.32	....	138	VI
		16	5.81	0.86	122	VI
		23	5.95		121	VI
		27½	4.41		99	III
		12½	5.76		115	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 5½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[3] Last feeding was about 19 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4] Last feeding was about 24½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

Table 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*W. P.* (cont.).	*mins.*	*gm.*			
Jan. 30	4.28 kilos	26	5.58	....	117	VI
		30	4.84	0.92	96	II
		30	4.70		95	III
		30	4.46		94	III
		30	4.60		97	II
		19	4.89		109	IV
Jan. 31	4.34 kilos	12	5.65	....	120	VI
		30	4.46	0.92	95	I
		30	4.78		102	III
		30	4.64		98	III
		30	4.36		96	II
		17	5.26		106	V
	W. P. (cont.), *5½ mos.*					
Feb. 11	4.57 kilos	36	7.02	....	135	VI
	D. Q., male, 4½ mos.					
Dec. 22	5.20 kilos	30	8.93	....	142	VI
		29	4.03	0.89	97	III
Dec. 23	5.35 kilos	26	7.13	....	130	VI
		30	4.48	0.81	106	I
		30	4.54		102	II
		30	4.06		98	II
	E. R., male, 3 mos.					
Apr. 11	4.59 kilos	16	5.44	....	139	V
		21	4.23	0.83	129	III
		33	4.62		133	IV
		57	4.38		130	IV
		17	4.16		126	V
Apr. 12	4.49 kilos	17	7.06	....	151	VI
		21	4.26	0.73	124	IV
		63	6.10		146	VI
		23	4.80		131	V
		24	3.58		122	II
Apr. 14	4.49 kilos	12	4.75	....	131	VI
		27	4.11	0.86	119	III
		31	4.32		124	IV
		22	4.50		124	II
		34	4.15		123	IV
		20	4.14		119	I
Apr. 15[2]	4.49 kilos	14	4.84	....	120	VI
		20	4.02	0.80	113	IV
		26	3.72		110	III
		25	3.67		114	III
		26	3.90		110	II
		30	3.94		117	IV
		21	3.37		106	II

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*K. R., male, 4 mos.*	*mins.*	*gm.*			
Apr. 5	3.14 kilos...........	78	4.51	....	116	VI
		23	2.74	0.83	91	II
		40	5.33		140	VI
Apr. 7	3.19 kilos...........	10	5.16	....	116	V
		30	3.20	0.88	107	I
		30	3.44		108	III
		27	3.31		108	II
		30	3.44		115	III
		26	3.14		106	II
	A. S., male, 3 mos.					
Mar. 28	6.04 kilos..........	11	9.00	....	143	V
		117	6.12	0.92	142 ?	VI
Mar. 29	6.10 kilos...........	37	8.51	....	...	VI
Apr. 1	6.02 kilos...........	16	4.73	0.81	117	IV
		23½	4.19		113	II
	E. S., female, 5 mos.					
Mar. 21	2.95 kilos...........	17	4.98	....	126	VI
		30	3.78	0.94	112	IV
		30	3.36		115	I
		30	3.30		107	III
		30	3.82		114	V
Mar. 22	3.00 kilos...........	13	4.29	....	99	V
		26	3.25	0.95	101	III
		20	4.11		114	IV
		30	3.34		98	I
		30	3.30		92	I
Mar. 25	3.03 kilos...........	19	4.52	....	119	V
		30	3.66	0.91	112	II
		30	3.56		115	III
		30	3.52		110	III
		30	3.34		100	III
	E.H.S.,male, 2½ mos.					
Nov. 13	2.85 kilos...........	17½	3.98	....	123	V
		38	3.43	0.90	116	V
		30	2.64		103	II
		30	2.88		108	IV
		33	3.38		121	VI
Nov. 21	2.85 kilos...........	17	2.68	....	114	III
		48	2.75	0.77	116	V
		34	2.51		113	II
		41	2.33		109	III
		24	3.00		123	V
	E. H. S.(cont.), *3 mos.*					
Dec. 1	2.88 kilos...........	40	2.93	....	83	V
		32	2.61	0.83	78	II
		25	3.12		91	IV
		33	3.05		89	IV
		32	3.69		109	V

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

Table 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*E.H.S.* (cont), *3½ mos.*	*mins.*	*gm.*			
Dec. 17	3.08 kilos...........	17	3.60	....	122	III
		24	2.93	0.97	113	III
		39	4.42		127	VI
		31	3.25		113	II
	E. H. S. (cont.), *4 mos.*					
Dec. 29	3.15 kilos...........	18½	3.76	....	116	IV
		24	3.68	0.92	112	III
		24	3.20		103	I
		30	3.38		107	II
		34	4.38		119	VI
	G. S., male, 2½ mos.					
Feb. 13	3.24 kilos...........	18	4.20	....	131	VI
		23	3.16	0.93	122	III
		22	4.36		134	VI
		26	4.50		132	VI
Feb. 14	....	32	5.64	....	150	VI
		12	3.85	0.92	129	V
		20½	3.04		122	II
		30½	3.80		123	V
		30	3.36		116	III
		29	3.06		110	II
Feb. 17	3.33 kilos...........	19	5.81	....	152	VI
		26	3.42	0.83	124	IV
		30	3.50		125	III
		30	3.42		124	IV
		30	3.26		121	III
		30	3.02		117	II
Feb. 19	3.33 kilos...........	30	3.48	0.88	125	IV
		30	3.56		130	III
		30	3.50		123	III
		30	3.32		121	III
		30	3.24		118	IV
	J. S., male, 5 mos.					
June 6	4.20 kilos...........	18	4.47	....	99	IV
		50	5.12	0.95	108	V
		40	5.63	....	123	VI
June 11	4.10 kilos...........	16	5.03	....	107	V
		20	4.77	....	103	V
		29	4.16	0.95	100	II
		30	4.44		105	III
		30	5.84		123	VI
	J. S. (cont.). *5½ mos.*					
June 12	4.05 kilos...........	19	6.63	....	122	VI
		30	6.40	0.98	121	VI
June 17	4.35 kilos...........	15	5.76	....	118	V
		20	4.53	0.97	102	III
		30	4.86		99	I
		23	4.62		105	IV

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number, III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. S.* (cont.)	*mins.*	*gm.*			
June 18[2]	4.40 kilos...........	15	6.16	....	112	V
		23	4.23	....	95	II
		30	4.58	....	105	I
		22	4.72	....	111	IV
		30	8.18	....	161	VI
June 19[3]	4.51 kilos...........	41	8.63	....	183	VI
		15	5.40	....	123	II
		20	4.56	0.88	115	III
		30	5.02		128	II
June 21[3]	4.47 kilos...........	30	4.54	....	115	II
		15	5.72	....	117	II
		24	4.75	....	116	II
June 24	4.50 kilos...........	15	6.60	....	132	V
		27	6.38	0.95	...	V
June 26	4.55 kilos...........	33	7.22	....	140	VI
		23	5.63	0.96	115	I
		25	6.10		129	V
		27	6.22		122	IV
June 27	*J. S.* (cont.), *6 mos.* 4.53 kilos...........	21	5.51	0.97	111	I
		33	5.22		120	II
Dec. 18	*P. S., male, 12 mos.* 7.00 kilos...........	31	9.02	....	137	VI
		19	7.29	0.84	114	IV
		31	6.83		100	II
		31	6.48		103	II
Dec. 19	6.85 kilos...........	17	8.49	....	118	V
		30	6.24	0.84	101	II
		30	6.98		100	II
		23	6.16		95	II
		20	8.91		124	VI
Dec. 19[4]	6.78 kilos...........	43	6.81	....	112	V
		30	5.76	0.83	102	I
		30	6.56		108	III
Dec. 20[5]	6.80 kilos...........	37½	7.70	....	128	VI
		30	5.46	0.71	98	II
		30	6.00		98	II
Dec. 20[6]	6.58 kilos...........	21	6.68	....	109	V
		30	5.20	0.71	96	II
		61	7.43		121	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2] Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

[3] On June 19 and June 21 last feeding was about 6 hours before the observations. Sterile water was substituted for food at subsequent times of feeding.

[4] Last feeding was about 5½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[5] Last feeding was about 19½ hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

[6] Last feeding was about 24½ hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

Table 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*H. T., male, 5½ mos.*	*mins.*	*gm.*			
Apr. 16	9.28 kilos...........	68	11.12	....	126	VI
Apr. 17	9.33 kilos...........	10	5.82	....	101	II
		26	6.55	0.95	101	II
		16	7.01		117	IV
	J. V., female, 3½ mos.					
Jan. 15	1.92 kilos...........	30	2.42	....	146 ?	II
		30	2.52	0.89	145 ?	II
Jan. 16	....	14	3.47	....	136	II
		30	1.44	0.90	130	I
		30	3.58		150	VI
Jan. 17	....	16	2.89	....	122	II
		28	2.55	....	129	IV
		20	3.66	0.83	160	VI
Jan. 20	....	36	3.55	....	151	VI
		30	2.26	0.79	131	II
		60	2.26		129	II
Jan. 21	1.94 kilos...........	30	4.18	....	156	VI
Jan. 24	....	22	3.08	....	121	V
		65	2.78	0.88	132	V
		22½	2.80		132	V
Jan. 25	....	39	3.72	....	145	VI
		30	2.22	0.85	126	III
		30	3.04		143	V
	J. V. (cont.), *4 mos.*					
Jan. 28	....	34	3.67	....	147 ?	V
		11	4.53	0.94	160	VI
		30	4.16		166	VI
Feb. 11	2.10 kilos...........	20	3.18	....	147	V
		23	2.48	0.94	138	IV
		27	4.00		149	VI
	J. V. (cont.), *4½ mos.*					
Feb. 15	2.20 kilos...........	30	2.74	....	141	II
		30	2.86	....	140	II
		30	2.82	....	144	III
		30	3.04	....	137	IV
		27	3.09	....	139	IV
Feb. 26	2.45 kilos...........	18	4.07	....	143	V
		66	3.65	0.91	142	V
		30	3.60		139	V
		30	3.22		131	IV
		30	3.36		130	II
Feb. 27	2.45 kilos...........	28	3.96	....	143	VI
		38	3.65	0.83	144	V
		30	3.34		135	III
		26	3.58		141	V
		30	3.28		136	III

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), *5 mos.*	*mins.*	*gm.*			
Mar. 5	2.56 kilos...........	17	3.56	....	142	III
		35	3.67	0.92	147	IV
		31	4.03		156	IV
		31	4.35		152	IV
		30	3.68		143	III
		30	3.62		138	II
Mar. 6	2.58 kilos..........	16	4.43	....	147	IV
		20	3.69	0.94	147	III
		30	3.76		146	IV
		30	3.68		140	III
		30	3.76		137	III
		30	3.24		131	I
		20	3.81		133	IV
	J. V. (cont.), *5½ mos.*					
Mar. 13	2.73 kilos..........	14	4.46	....	168	IV
		25	3.91	0.91	156	III
		30	3.86		150	IV
		30	3.76		146	II
		30	3.58		141	II
Mar. 27	2.98 kilos..........	14	4.89	....	144	IV
		30	3.90	0.89	132	II
		30	4.08		134	III
Mar. 29	3.08 kilos..........	33	5.27	....	148	VI
		30	3.82	0.94	130	II
		29	3.87		129	III
	J. V. (cont.), *6 mos.*					
Apr. 8	3.17 kilos..........	45	4.13	0.82	145	V
		25	3.62		132	II
		20	4.17		134	IV
		22	3.68		130	III
		26	3.65		127	III
Apr. 9	3.17 kilos..........	12	4.40	....	144	I
		54	5.02	....	151	V
		52	5.30	....	159	VI
Apr. 10	3.17 kilos..........	69	4.79	....	148	VI
		22	3.74	0.84	137	III
		24	4.20		141	IV
Apr. 17	2.89 kilos..........	28½	3.43	0.79	123	V
		24½	3.45		124	IV
Apr. 18	2.98 kilos...........	10	3.60	....	130	I
		22	3.27	0.82	123	II
		18	3.63		128	III
		24	3.53		126	IV
		36	3.60		126	IV
		29	3.39		128	IV

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

Table 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), *6½ mos.*	*mins.*	*gm.*			
Apr. 21[2]	2.98 kilos..........	52	4.26	....	133	VI
		26	3.55	0.79	123	III
		33	3.91		132	V
		28	3.75		126	III
		21	3.26		122	III
		21	3.43		123	III
Apr. 22[3]	2.93 kilos..........	24	4.53	....	136	V
		36	4.25	0.81	140	VI
		20	3.21		110	II
		26	3.39		115	III
		28	3.02		110	III
		30	3.24		114	III
Apr 30.	3.13 kilos..........	29	4.86	....	147	V
		20	3.78	0.85	127	III
		40	4.76		146	VI
		12	6.50	....	169	VI
	J. V. (cont.), *7 mos.*					
May 1[4]	3.13 kilos..........	40	3.81	0.78	130	V
		10	3.96	....	135	IV
		29	3.91	0.73	134	V
		24	4.55		147	VI
		30	4.84		154	VI
	J. V. (cont.), *7½ mos.*					
May 27	3.25 kilos..........	17	5.51	....	138	V
		20	4.17	0.88	122	II
		30	4.52		122	III
		30	4.40		119	III
		24	4.03		118	II
		20	4.98		134	V
June 4	3.30 kilos..........	88	5.17	....	129	VI
		15	5.80	....	149	VI
	J. V. (cont.), *8 mos.*					
June 9	3.50 kilos..........	40	5.79	....	145	VI
		11	4.69	....	131	II
		60	5.42	0.87	142	V
June 10	3.35 kilos..........	48	5.80	....	149	VI
		32	5.74	....	151	VI
June 12	3.35 kilos..........	16	5.48	....	137	IV
		19	4.58	0.94	129	II
		30	5.86		141	V
June 13	3.38 kilos..........	15	5.92	....	134	V
		23	4.43	0.90	123	III
		30	4.70		120	III
		47	5.67		136	VI

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[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table. 31, p. 142.

[2] Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[3] Last feeding was about 6 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[4] Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II. Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), *8½ mos.*	*mins.*	*gm.*			
June 25	3.40 kilos...........	17	5.29	....	130	V
		22	4.42	0.88	125	III
		25	4.70		124	III
		25	4.20		122	IV
		30	5.62		140	VI
June 30	3.39 kilos...........	17	5.15	....	142	IV
		26	4.59	0.92	135	IV
		22	4.36		129	III
		27	4.67		127	IV
		26	4.68		125	IV
	P. W., male, 7 mos.					
April 1	7.11 kilos...........	21	7.69	....	144	V
		14	7.54	0.86	130	IV
		10	7.20		134	V
		30	6.20		120	II
		30	6.40		121	III
		30	6.40		122	III
		30	6.54		125	IV
April 3	7.11 kilos...........	30	6.50	0.84	127	I
		28	5.89		117	I
		17	6.53		119	II
		23	6.13		115	II
		28	6.56		124	IV

[1] Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

While the data given in table 23 are made the basis of the discussion of our results in Part III of this publication, they may likewise be used for the discussion of many problems which have not been considered at this time. Furthermore, observations are still in progress in which supplementary evidence is rapidly being accumulated. Hence we wish it clearly understood that the data in table 23 are recorded here not only for present use, but for deferred discussion, in another place, of the many problems connected with the study of the metabolism of infants, such as the influence upon metabolism of crying, intense muscular activity, subnormal or febrile temperatures, and various distinctly pathological conditions.

PART III.

DISCUSSION OF RESULTS.

In a recent study of the metabolism of diabetics in this laboratory, it was found that the experiments were much lessened in value because of the lack of suitable normal controls. This led us to believe that our best service to pediatrics would be to determine the normal metabolism of infants. Accordingly, while a few observations were made with distinctly pathological cases, our data were secured for the most part with normal or under-weight infants.

One important problem in such an investigation is the relationship between muscular repose and metabolism. The graphic registering device for recording the muscular movements of the infant gave us an exceptionally good opportunity to obtain data regarding this relationship, which was made an object of special study in this investigation.

Furthermore there is a wide difference of opinion among physiologists as to whether or not during sleep there is a lowered metabolism, some writers maintaining that it is possible for a man to relax his muscles voluntarily so as to have a metabolism while awake as low as that during sleep, the sleep of itself having no influence upon the metabolism. With infants it is almost impossible to obtain periods of muscular repose while the infant is awake and it was recognized at once that only those periods when the infant was asleep could reasonably be looked upon as periods of complete muscular rest. It was hoped, however, that certain periods might throw light upon the effect of sleep upon metabolism.

The influence upon metabolism of the ingestion of food also received some attention in this research as an increased metabolism following the ingestion of protein, fat, or carbohydrate has been noted in many observations made with adults. This increase in the metabolism has been variously ascribed to the mechanical work of digestion, to the so-called specific dynamic action of the foodstuffs, or, as is now the belief in this laboratory, to the stimulating effect of certain substances—the specific katabolic stimuli—absorbed from the food material through the alimentary tract, and there carried by the blood to the cells to stimulate them to greater activity. Reasoning from the results obtained with adults, an infant receiving nutriment should have a greater metabolism than when he is without food; and it was hoped that experiments could be made with normal infants in which the influence of the ingestion of food could be more carefully studied. Difficulty was found at the outset in securing periods of quiet with infants under any conditions, but greater difficulty was had when the infants were not fed. Our experience, we admit, is very limited and we hope to profit by the suggestions of other observers, particularly Schlossmann and Murschhauser, in securing further aid in this important study. The data we have thus far obtained are somewhat fragmentary and by no means convincing; in fact, they hardly justify an extended discussion.

Our chief aim, therefore, was to study the metabolism of normal infants under conditions approximating the ideal, these infants to be selected, first, with varying ages; second, with varying weights; and third, of both sexes. That a sufficient number of observations could be made in one or two years to establish a standard for the normal metabolism of infants was hardly to be expected, but we at least hoped to make a good beginning, knowing that in subsequent years our data would be supplemented[1] and our findings from time to time revised.

Perhaps the most important abstract problem which is met with in an investigation of this nature—a problem interesting alike to both physiologists and pediatricians—is the cause of the variations in the metabolism of the infant. For instance, is the metabolism proportional to the active mass of protoplasmic tissue? There is clearly a suggested relationship between the metabolism and the body-weight, but the metabolism per kilogram of body-weight is by no means an index of the mass of active protoplasmic tissue; nevertheless some relationship should exist. At present we are wholly unable to determine the total mass of the active protoplasmic tissue in an infant's body. Unquestionably much of the gain in weight of a growing infant is due to the storage of fat; it is likewise certain that the gain in weight due to the nitrogen retained may not all be due to the formation of active protoplasmic tissue; thus the problem is doubly complicated.

We may further ask "Is the metabolism proportional to the body-surface?" Such a stimulating suggestion has been made by Rubner, who computed in his earlier experiments the relationship between body-surface and heat-production, finding it to be relatively constant for practically all species of warm-blooded animals, ranging in size from a horse to a mouse. In round numbers Rubner finds this relationship to be not far from 1,000 large calories per square meter of body-surface per 24 hours. To throw light upon the important physiological problem of the relationship between the body area and the total metabolism was one of our main problems.

PULSE-RATE.

Very little attention has been paid to the normal pulse-rate of infants, so that only such general statements as the following from Holt[2] are found in the text books:

"The pulse in early life is not only more frequent but it is very much more variable than in adults. The following is the average pulse-rate of healthy children during sleep or perfect quiet:

6 to 12 months, 105 to 115 per minute; 2 to 6 years, 90 to 105 per minute.

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[1] As our page proof goes to press, we are informed that Hoobler and Murlin have very recently duplicated some of our experiments and although their observations include but two atrophic infants, they report that their findings are in full accord with ours. Their results were reported under the title "The energy metabolism of normal and marasmic children" at the fifty-eighth meeting of the Society for Experimental Biology and Medicine, in New York, April 15, 1914, and also at a meeting of the Inter-Urban Club, New York, April 17, 1914.

[2] Holt, Diseases of infancy and childhood, New York and London, 1911, p. 565.

"The pulse is a little more frequent in females than in males. Muscular exercise or excessive excitement increases the pulse-rate from 20 to 50 beats. Very trivial causes disturb not only the frequency but the force of the pulse."

Some figures are given in a few observations by Townsend,[1] which show that the pulse-rate of the crying baby is more rapid than that of the quiet baby, but no definite, continuous data have been reported other than the observations published by the writers in a previous paper.[2]

An examination of the records thus far given in this report shows that it is of the greatest moment whether the infant is asleep or awake when the pulse observations are taken. It is probable that most of the records of pulse-rate previously reported by observers have been made when the infants were awake and possibly more or less restless. But little data are available, therefore, as to the minimum pulse-rate and the length of time required for the pulse to reach the minimum after muscular activity.

PRELIMINARY OBSERVATIONS.

To secure more definite information on this subject, observations were made by one of us (F. B. T.) at the Boston Lying-in Hospital and the Directory for Wet Nurses at the Massachusetts Babies' Hospital, in which a stethoscope was attached directly to the infant. Records could thus be taken by skilled nurses without disturbing the subject. From this extended series, a few typical pulse curves have been selected for reproduction here, including two previously published in the paper referred to. These give a fair index of the fluctuations which would normally be expected with infants of different ages and varying activity.

The curve shown in figure 11 was obtained with S—ns at the age of 3 days, the records being taken practically every 5 minutes between $7^h 5^m$ p. m. and $6^h 28^m$ a. m. The maximum pulse-rate was 161 beats and the lowest observed value was 101 beats. When the curve is carefully examined, it will be seen that there was a general tendency for the pulse-rate to fall to a minimum of not far from 112 to 115, although the line is characterized by rapidly varying fluctuations.

The second curve (see figure 12) was obtained 5 days later with the same infant, and shows the general irregularities of the first. The maximum record is even higher, *i. e.*, 174, while the minimum is 108. During the latter part of the night, the minimum count was not far from 115 beats for several minutes.

A similar set of observations was made with Dow, 4 days old, covering the same period of time as those with the first infant (see figure 13). The maximum pulse-rate with this infant was 165 and the minimum

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[1] Rotch, Pediatrics, 5th ed., 1907, Philadelphia and London, p. 67.

[2] Benedict and Talbot, Am. Journ. Diseases of Children, 1912, **4**, p. 129. Since this was written the valuable article by Katzenberger, Zeitschr. f. Kinderheilk., 1913, **9**, p. 167, entitled *Puls und Blutdruck bei gesunden Kindern*, has appeared.

110. On one or two occasions the pulse-rate seemingly approximated a minimum of 112 to 113.

With Weldon, 8 days old, the maximum was 161, and the minimum 111. Here again the curve, which is given in figure 14, is characterized by rapid and sudden fluctuations of considerable extent, although at times there is a tendency for the curve to reach a minimum of about 115.

With Herbert W., 5 weeks old, the pulse records were obtained throughout the night for a period of 12 hours and are given in figure 15. The maximum record was 134 and the minimum 98. Several times during the night, the pulse-rate reached a minimum of about 100.

Another 12-hour observation was obtained with Rita McL., 3 months old, giving a maximum pulse-rate of 140 and a minimum of 87 (see figure 16). A minimum average is shown at not far from 90.

Paul, 3 months old, in the same period of time had a maximum pulse-rate of 154 and a minimum of 97, with an average minimum of approximately 100. The curve is given in figure 17.

Tremballe, 5 months old, gave a maximum of 147 and a minimum of 83. During the latter part of the night, the minimum records showed an average of not far from 90 (see figure 18).

With Christine D., 7 months old, the maximum record was 139, while the minimum pulse-rate was 90, with the curve (figure 19) seeking an average minimum of 90 during the latter part of the night.

While all the curves indicate a quick reaction to muscular activity of any kind, it would appear that the younger the infant, the greater these fluctuations were and the more sensitive the infant was to changes in muscular activity. The average minimum record for infants 8 days old or under was approximately 115, while infants of 3 months or over showed an average minimum of about 90. After nursing, the pulse-rate was always high, but would subsequently reach its normal level in about 30 minutes if the infant remained quiet. Although the difference was not very great, the curves as a general rule show that the older the infant, the more rapid was the return to the average pulse-rate after nursing.

While the recent observations of Katzenberger[1] are of great importance in supplementing our previous scant knowledge regarding the average pulse-rate of infants and hence make any extensive comparison of our data on different infants entirely unnecessary, we believe that our observations show for the first time the large variations in pulse-rate of afebrile infants during the night when extraneous muscular activity is presumably less than during the day. We may correctly infer that the fluctuations in the pulse-rate shown in these records are probably exceeded by variations during the day and, consequently, in the ordinary daily life of infants we have to deal with very wide fluctuations in pulse-rate. Comparative data for different infants, to be of value, should therefore be obtained at the minimum. This can only be secured during deep sleep.

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[1] Katzenberger, *loc. cit.*

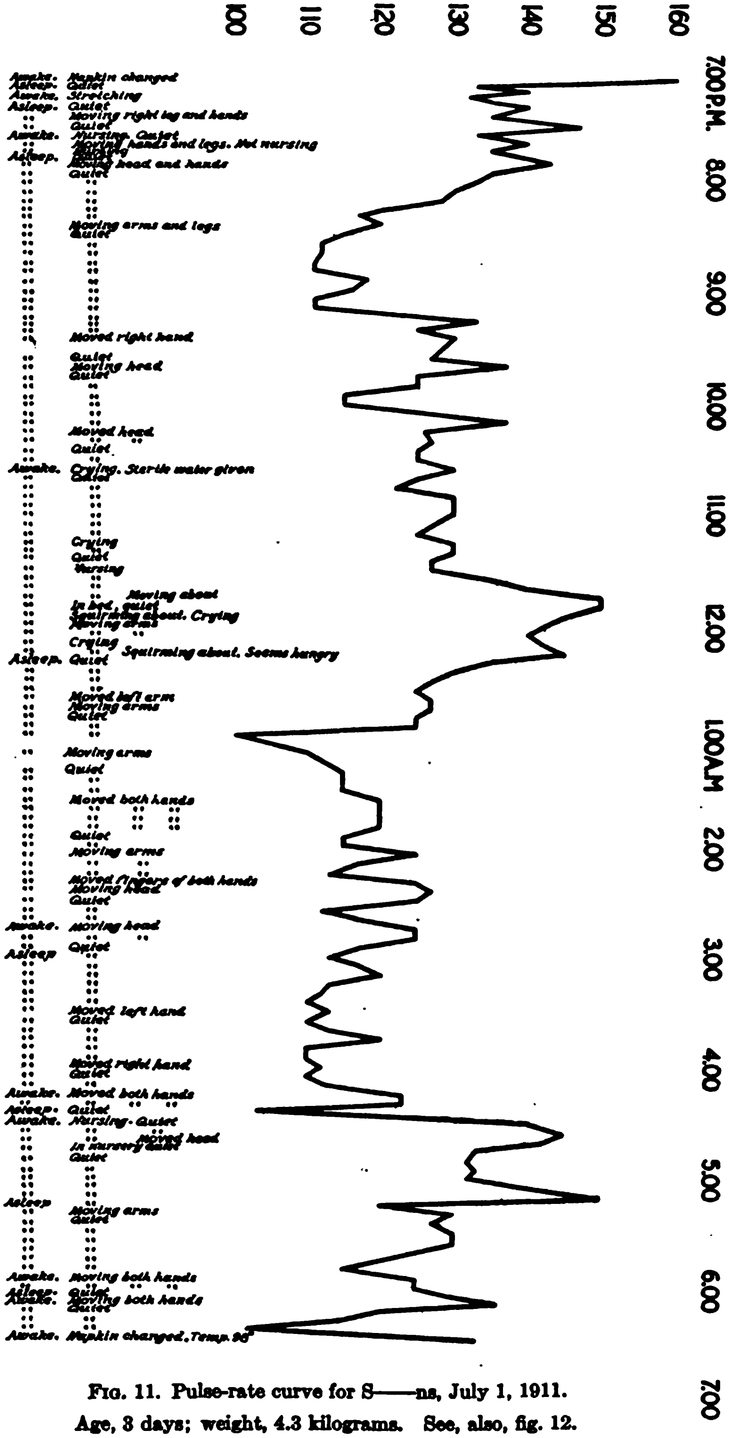

FIG. 11. Pulse-rate curve for S——ns, July 1, 1911.
Age, 3 days; weight, 4.3 kilograms. See, also, fig. 12.

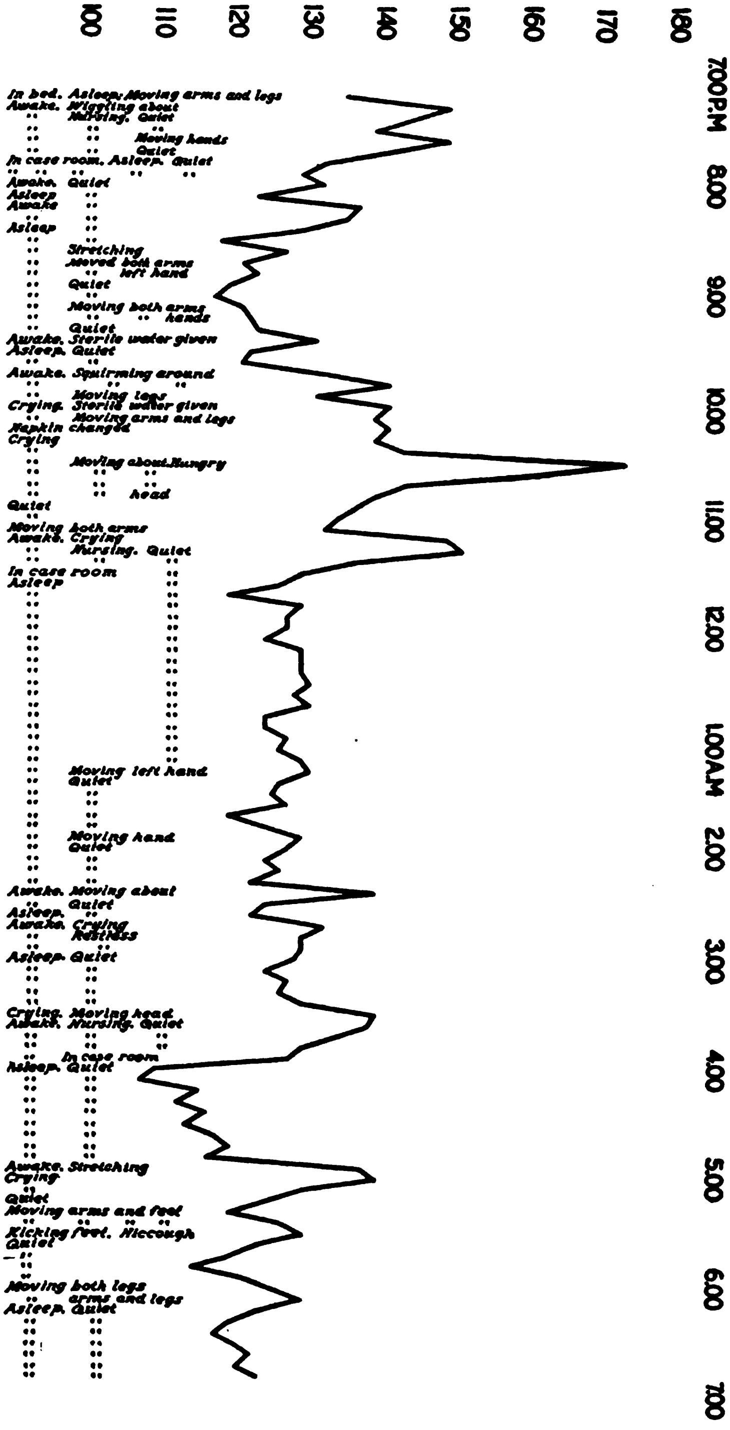

FIG. 12. Pulse-rate curve for S——ns, July 6, 1911. Age, 8 days; weight, 4.0 kilograms. See, also, fig. 11.

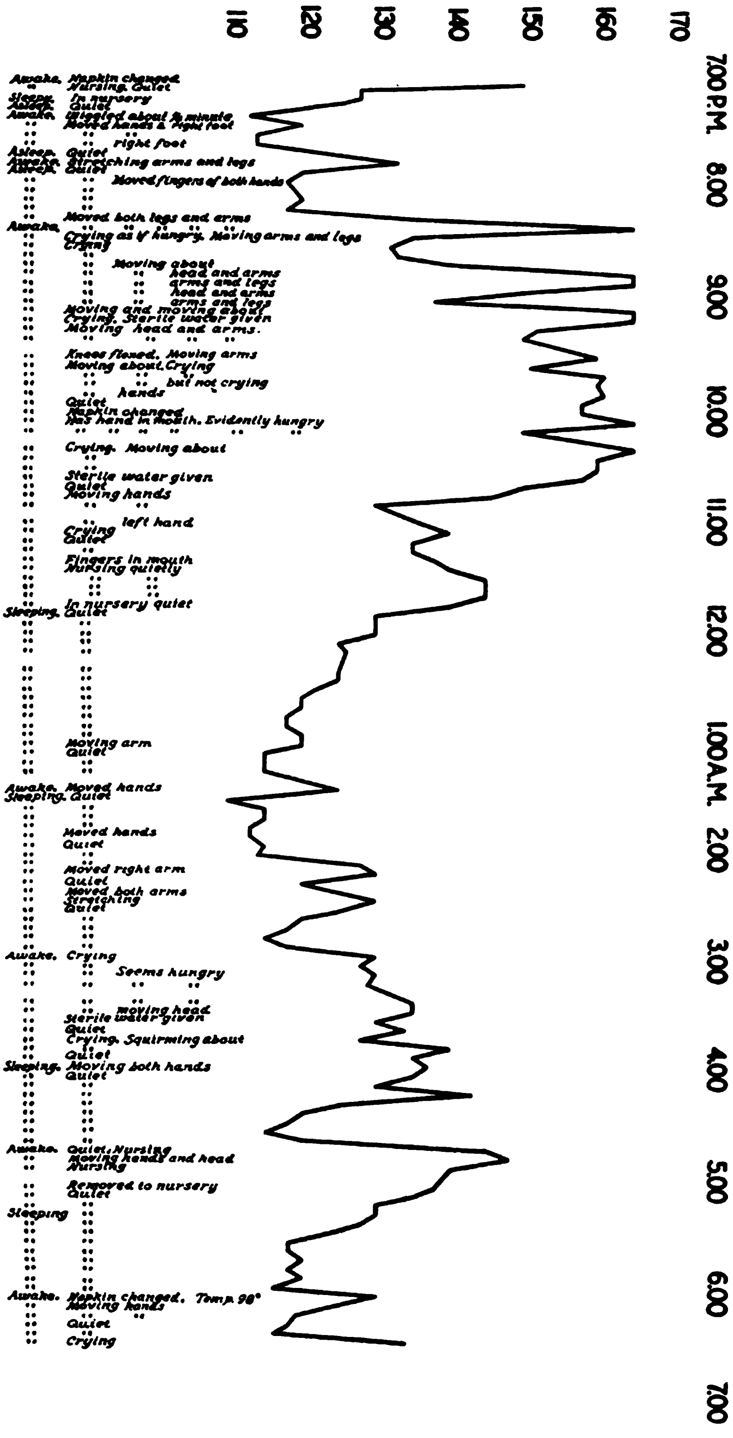

FIG. 13. Pulse-rate curve for Dow, July 1, 1911.
Age, 4 days; weight, 2.5 kilograms.

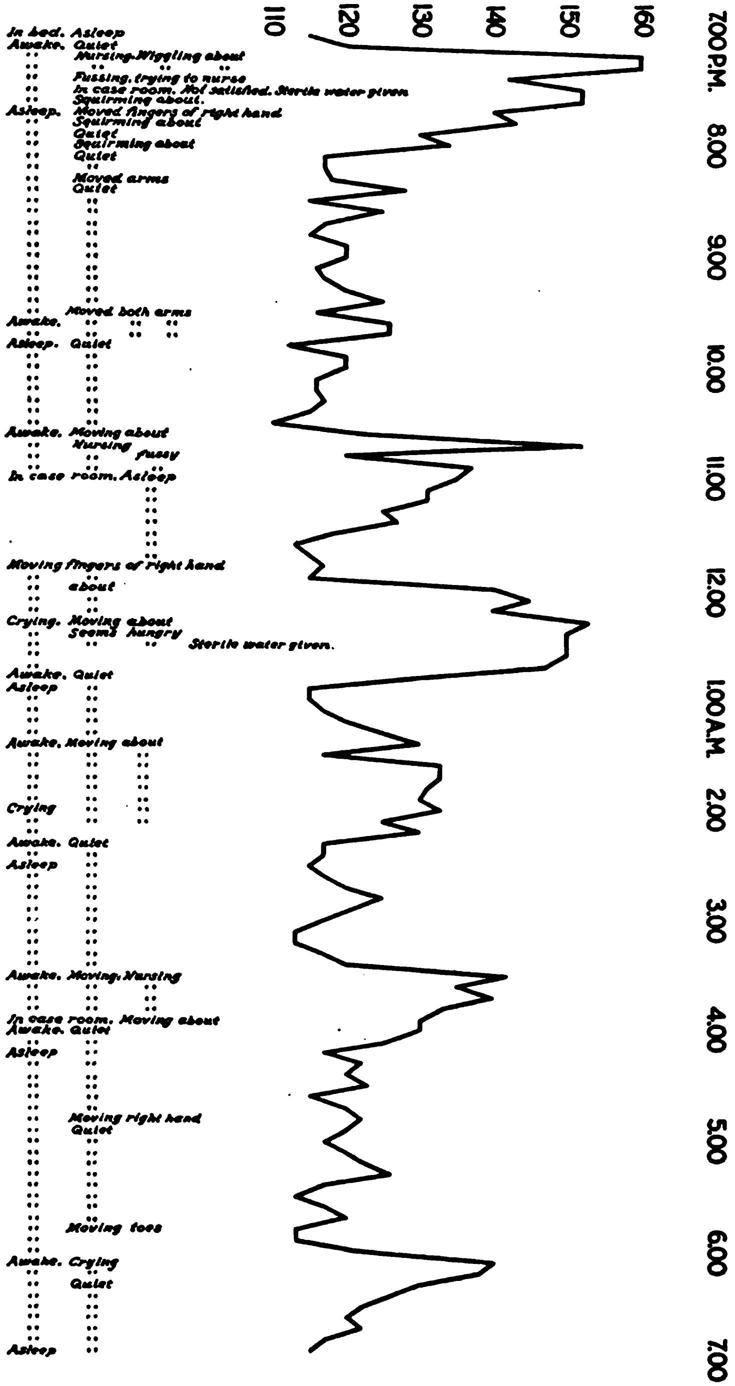

FIG. 14. Pulse-rate curve for Weldon, July 6, 1911.
Age, 8 days; weight, 3.0 kilograms.

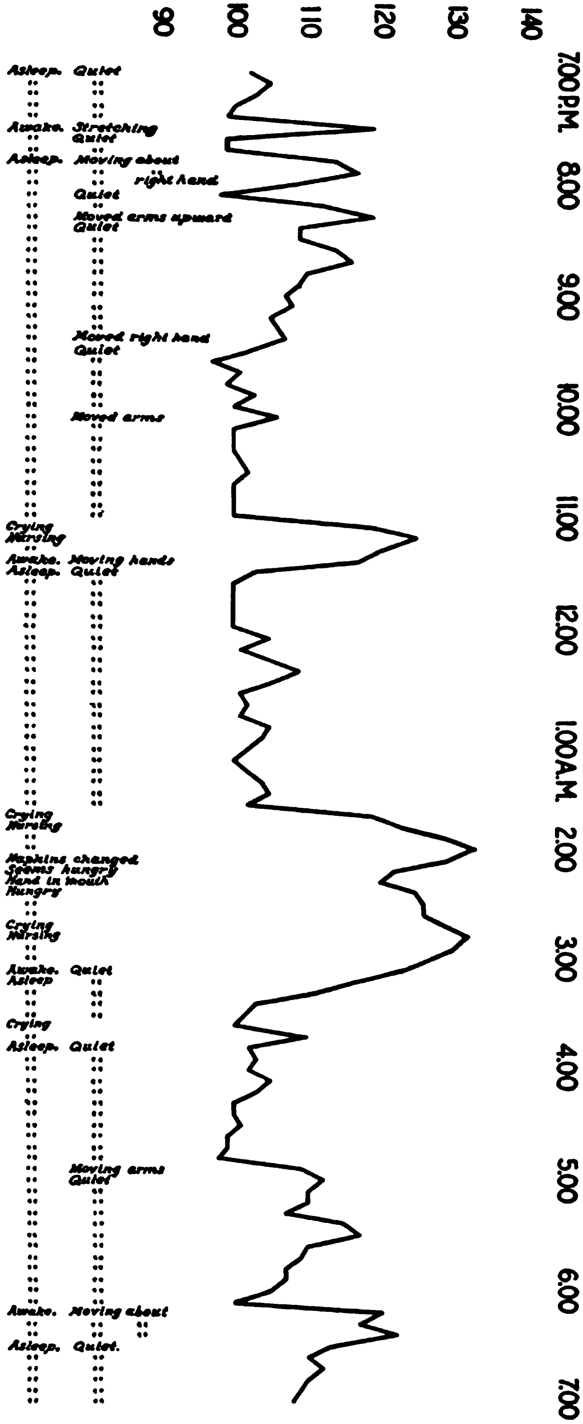

FIG. 15. Pulse-rate curve for Herbert W., July 13, 1911.
Age, 5 weeks; weight, 4.8 kilograms.

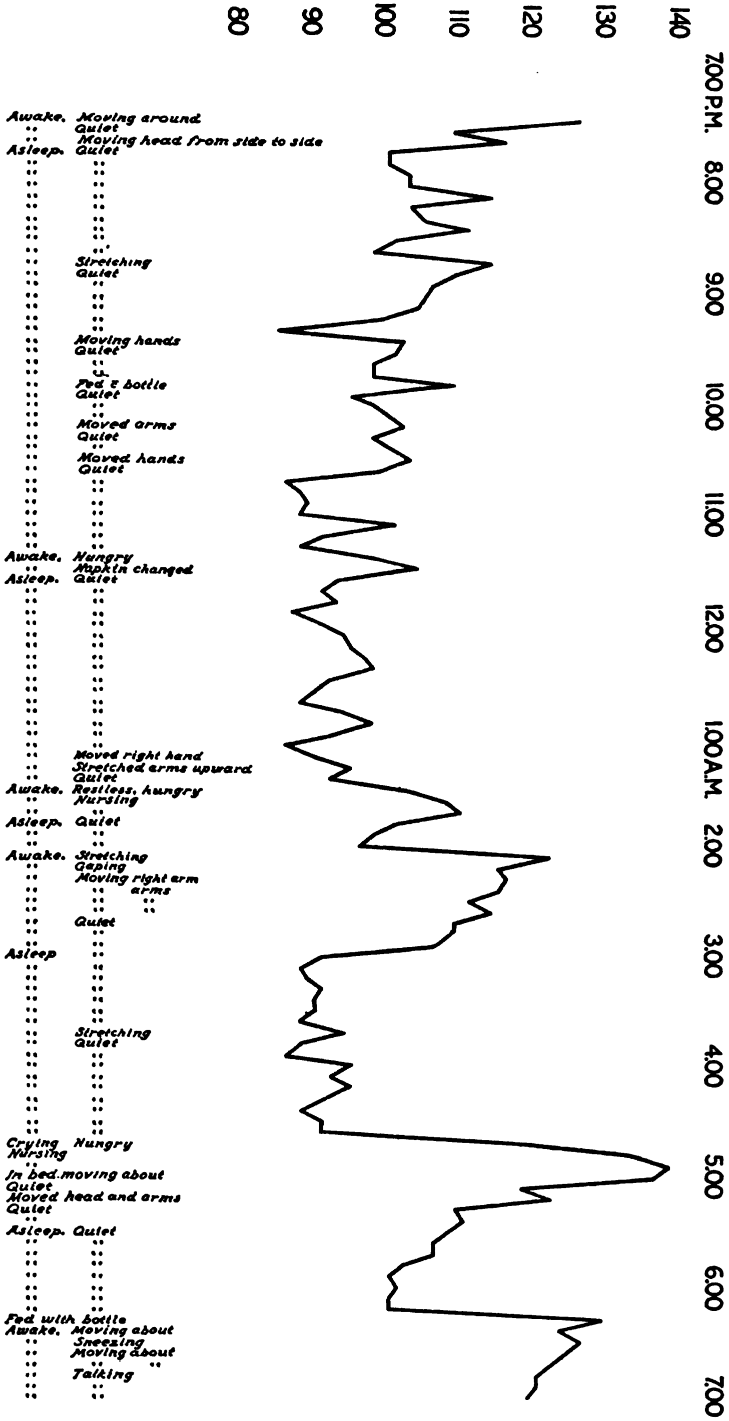

FIG. 16. Pulse-rate curve for Rita McL., July 14, 1911.
Age, 3 months; weight, 6.6 kilograms.

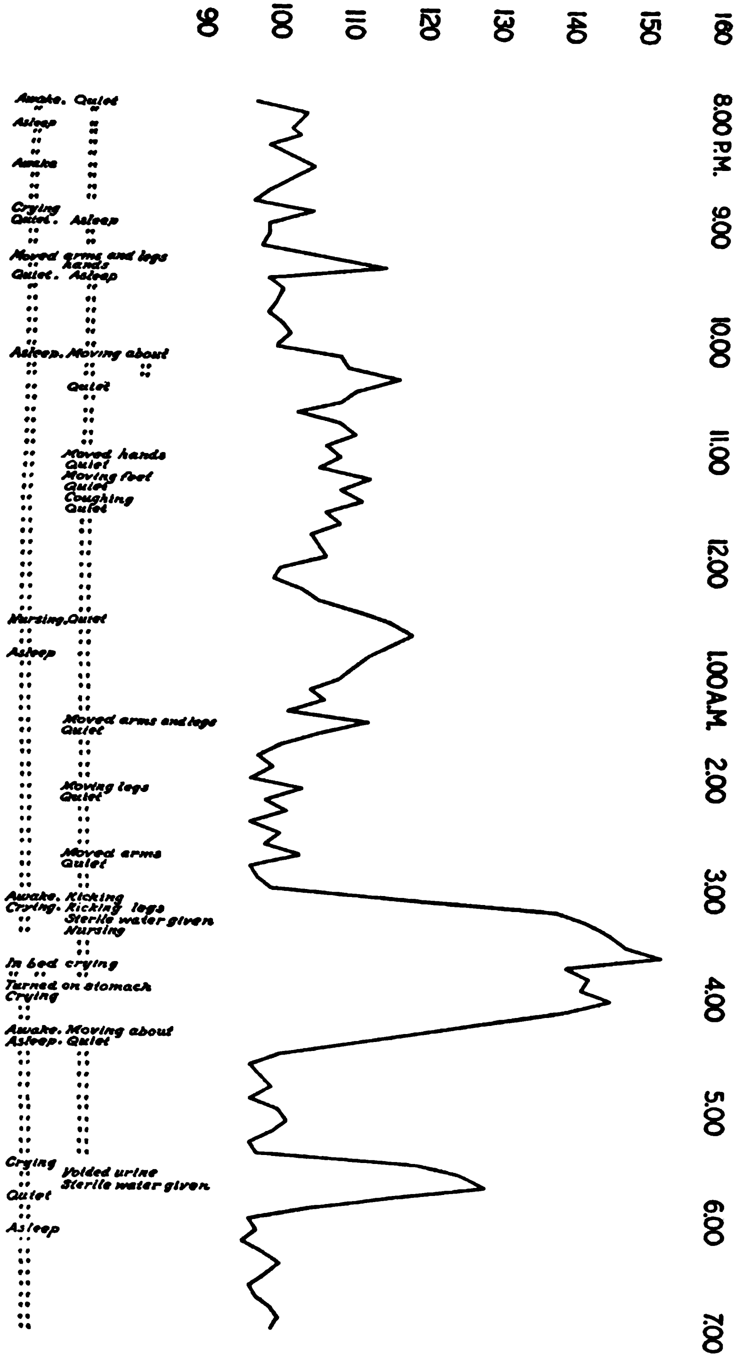

FIG. 17. Pulse-rate curve for Paul, July 12, 1911.
Age, 3 months; weight, 5.5 kilograms.

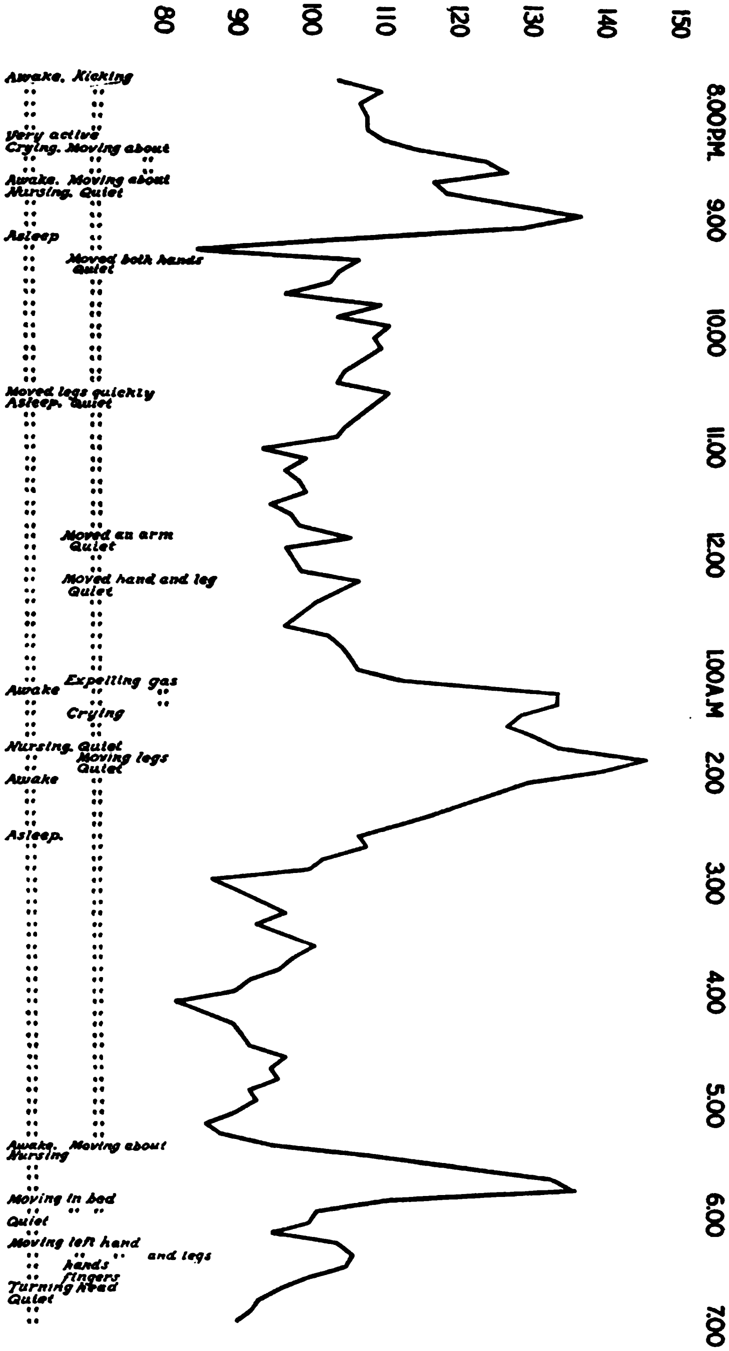

FIG. 18. Pulse-rate curve for Tremballe, July 12, 1911.
Age, 5 months; weight, 5.7 kilograms.

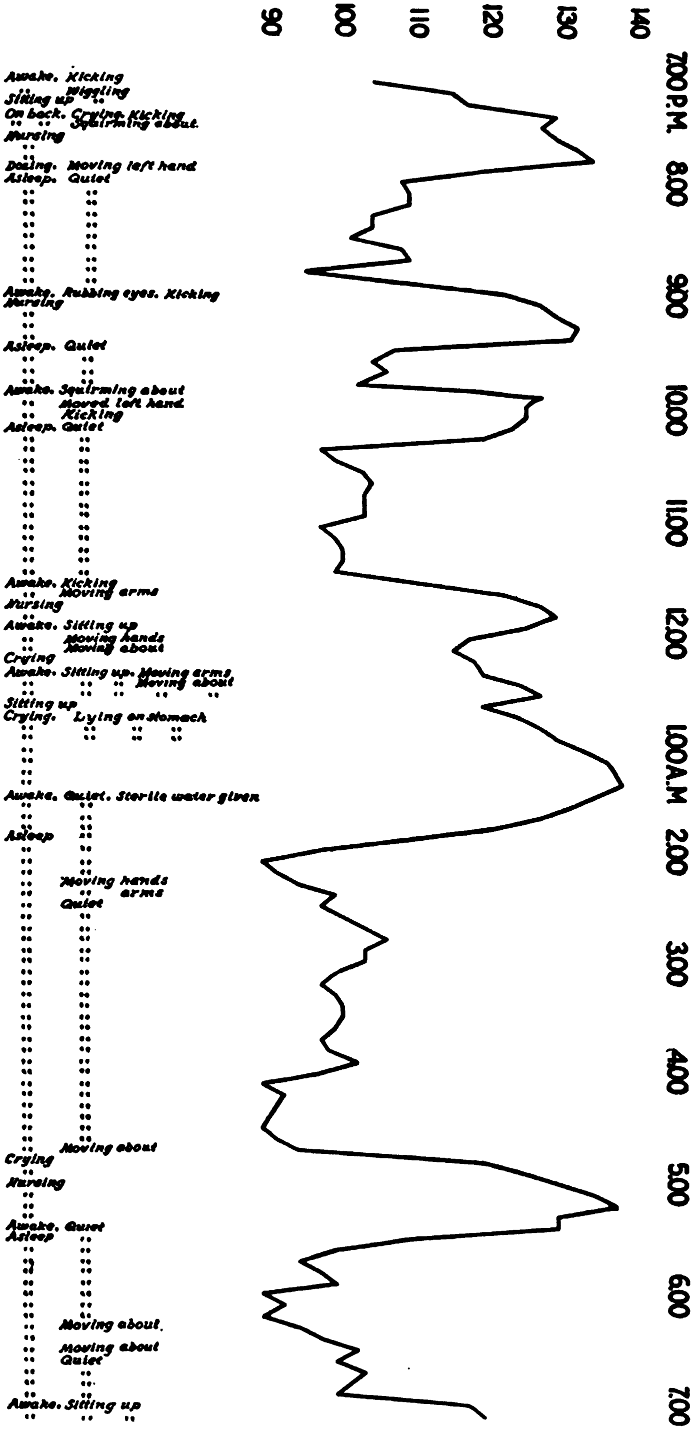

FIG. 19. Pulse-rate curve for Christine D., July 13, 1911.
Age, 7 months; weight, 7. 3 kilograms.

RECORDS OBTAINED DURING OBSERVATIONS WITH THE RESPIRATION APPARATUS.

The observations just discussed were only preliminary in character and were necessarily liable to more or less error. We have, however, a large number of pulse records which were subsequently made while the infant was under constant conditions in the respiration chamber. These records were likewise obtained by the use of the stethoscope according to the method previously described.[1]

It was frequently noted by the observer that the pulse-rate varied considerably during the minute of counting, particularly with very young infants. Thus, while the pulse-rate might be 20 beats in the first 10 seconds of the count, during the next 10 seconds it might fall to 18 beats, with similar variations throughout the whole minute. The pulse-rate was usually counted for one complete minute, but if the infant was crying it was counted for a half minute. At times when it was impossible to hear the pulse beat, the regular rhythm was counted by the observer and the count resumed by picking up the beats again when they became audible. Except during periods of crying, the pulse beats could be counted with a high degree of accuracy, but with the rapid pulse of severe crying slight errors unquestionably crept into the count. The arrhythmical pulse-rate of normal infants has recently been very extensively studied by Hecht.[2]

As already stated, we feel that the possibility for error in this method of taking the pulse records is too great and that some automatic form of recording the pulse-rate should be substituted. Every effort was made, however, to obtain pulse records as nearly exact as possible with this method, so that the pulse curves secured during the observations with the respiration chamber may very properly be carefully studied and relationships established with other records obtained at the same time.

RELATIONSHIP BETWEEN PULSE-RATE AND MUSCULAR ACTIVITY.

The simultaneous measurements of the pulse-rate by means of the stethoscope and of the muscular activity by the kymograph enable us to make sharp comparisons between these two factors. Such a comparison is made in figures 20 and 21, in which the kymograph curves obtained with two subjects are compared with the curves for the records of the pulse-rate during the same period of time.

The pulse and activity curves obtained for E. R. in the observation on April 12, 1913, are given in figure 20. The kymograph record shows that after a period of activity from 3h 3m p. m. to about 3h 16m p. m. there was a short period of comparative quiet, *i. e.*, from 3h 16m p. m.

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[1] See p. 61.

[2] Hecht, Der Mechanismus der Herzaktion im Kindesalter, seine Physiologie und Pathologie, Ergebnisse d. inn. Med. u. Kinderheilkunde, 1913, **11**, p. 324.

to $3^h 36^m$ p. m., and that the last period from $5^h 07^m$ p. m. to $5^h 31^m$ p. m. was also sufficiently quiet to be characterized as activity II[1]. The remainder of the time the infant was quite active, so that experimental observations of the minimum metabolism were impossible. A close examination of the kymograph and pulse curves shows that there is a striking parallelism between them. Thus, from $3^h 03^m$ p. m. to about $3^h 16^m$ p. m., the infant was restless, with a high pulse-rate, while between $3^h 16^m$ p. m. and $3^h 36^m$ p. m., the activity was at a minimum and the pulse-rate was low. About $3^h 39^m$ p. m. the pulse-rate again rose, the rise being accompanied by increased external activity. This reached a maximum about 4 o'clock and a period of decreasing activity followed until the infant became quiet at about $5^h 7^m$ p. m. From that time until it waked up, just before the end of the observation, the infant was quiet with a minimum pulse-rate. Thus we see complete uniformity in both curves.

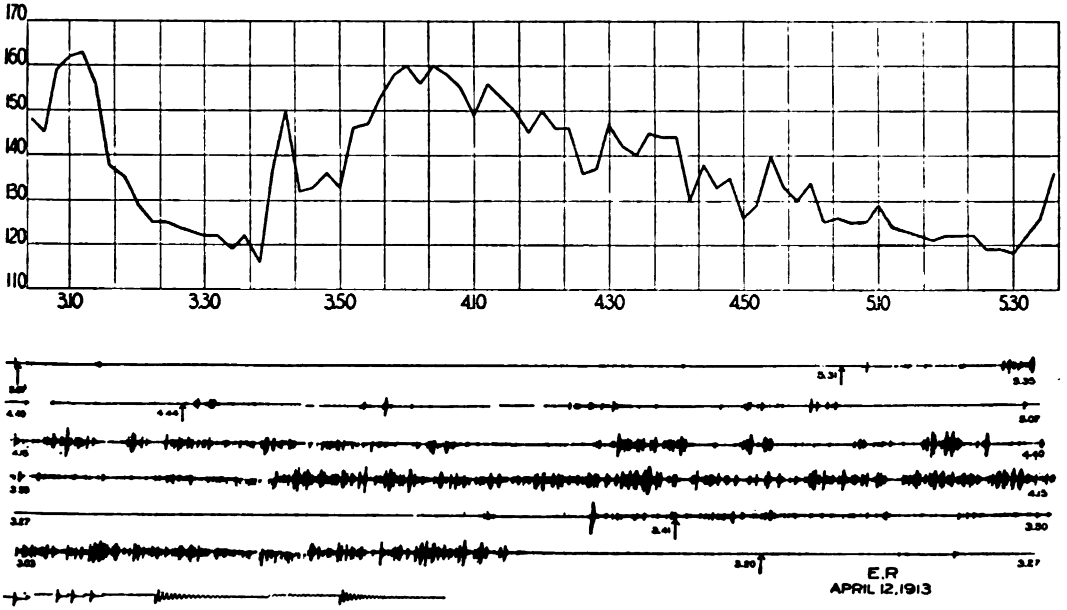

FIG. 20. Pulse-rate and kymograph curves for E. R., April 12, 1913.

A second set of curves, which was obtained with E. N. on May 23, 1913, is given in figure 21. These curves also show a general parallelism between the activity and the pulse-rate, with an apparently anomalous condition between $4^h 25^m$ p. m. and $4^h 40^m$ p. m. At this time the pulse-rate was distinctly higher, while the kymograph record, although not a perfectly smooth line, indicates no major movements. Another instance of fluctuating pulse-rate unaccompanied by changes in the kymograph record is seen in the period between $5^h 10^m$ p. m. and $5^h 30^m$ p. m. We thus have a general indication of uniformity between the pulse curve and the kymograph record, with a possibility of considerable fluctuation in the pulse-rate which is unaccompanied by external muscular activity. This feature will receive special consideration later.

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[1] For a discussion of the method adopted for designating the various degrees of muscular activity, see p. 130 and 136.

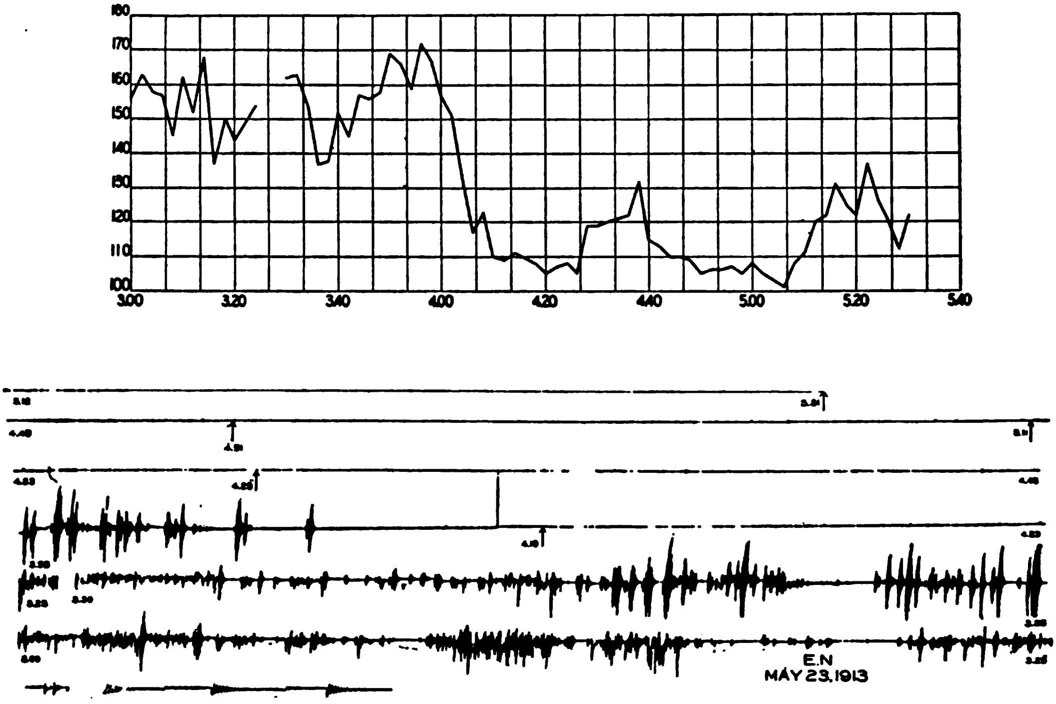

FIG. 21. Pulse-rate and kymograph curves for E. N., May 23, 1913.

An examination of the 193 kymograph records obtained in this series of experiments with infants shows the same general uniformity between the pulse-rate and the muscular activity as do the two specimen sets of observations given in figures 20 and 21. There are, however, a sufficient number of well-defined instances of alterations in the pulse-rate, unaccompanied by changes in muscular activity, to justify the assumption that an increase in pulse-rate is not necessarily a result of extraneous activity.

As further evidence of the uniformity between muscular activity and pulse-rate, particularly during periods of restlessness, we present in figures 22 to 37 comparisons of portions of kymograph and pulse-rate curves obtained with a number of subjects. This collection of kymograph curves is also of particular interest, since they are selected, for the greater part, to show the change from activity to repose, or the reverse. The bracketed portions of the kymograph curves correspond to the pulse curves.

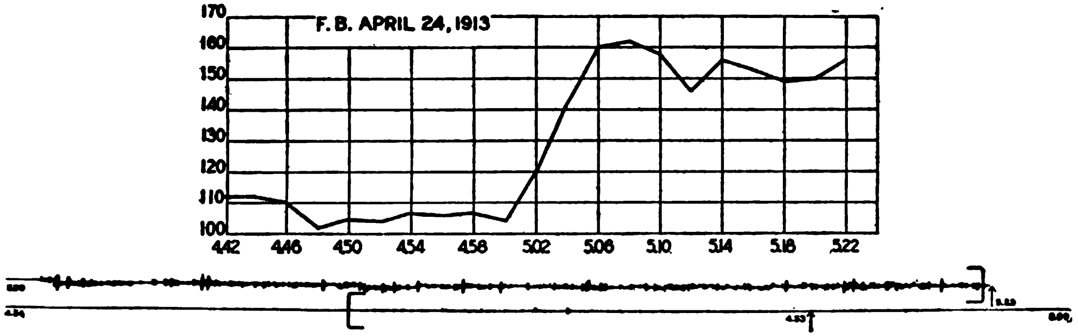

FIG. 22. Pulse-rate and kymograph curves for F. B., April 24, 1913.

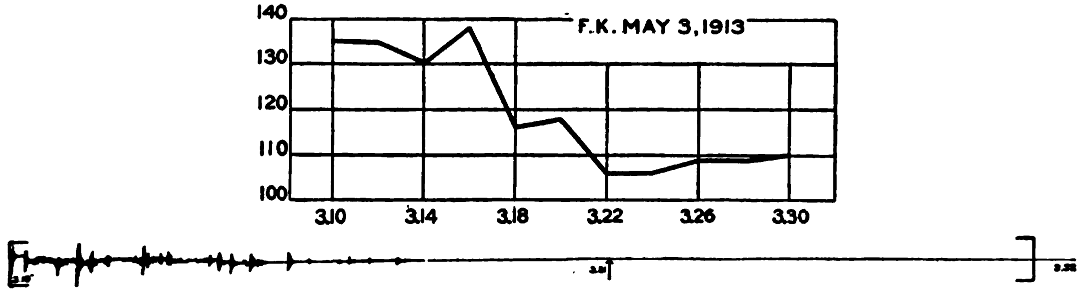

FIG. 23. Pulse-rate and kymograph curves for F. K., May 3, 1913. 3h 10m p. m. to 3h 30m p. m.

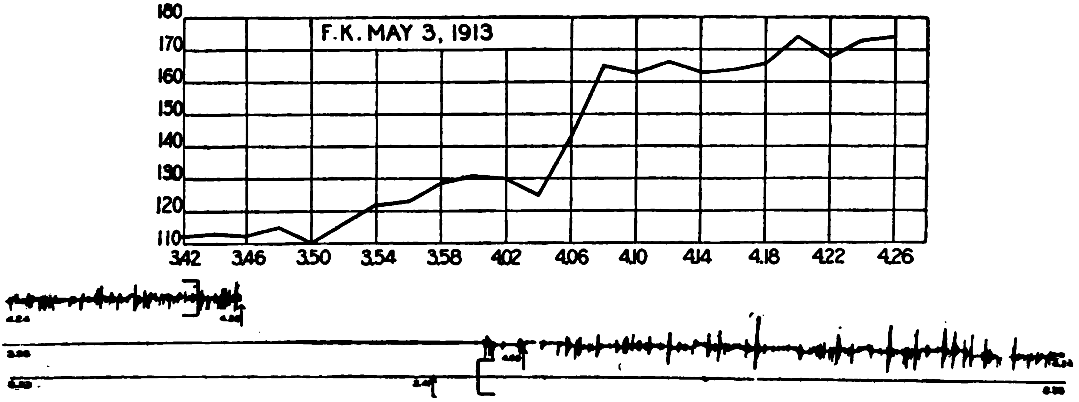

FIG. 24. Pulse-rate and kymograph curves for F. K., May 3, 1913. 3h 42m p. m. to 4h 26m p. m.

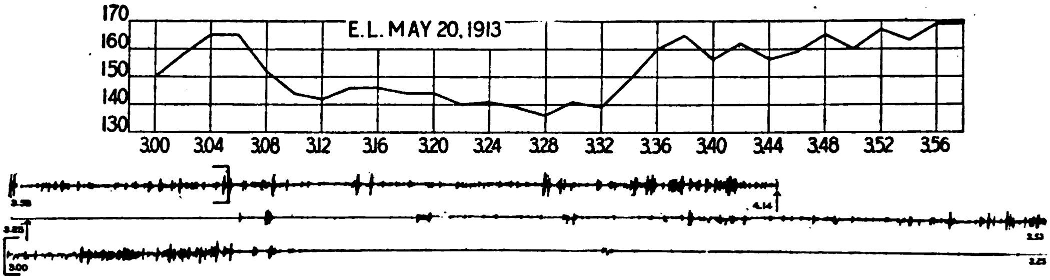

FIG. 25. Pulse-rate and kymograph curves for E. L., May 20, 1913.

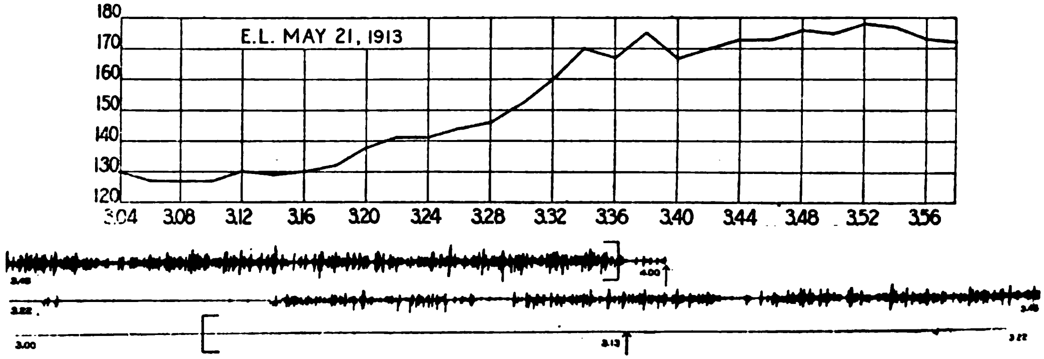

FIG. 26. Pulse-rate and kymograph curves for E. L., May 21, 1913.

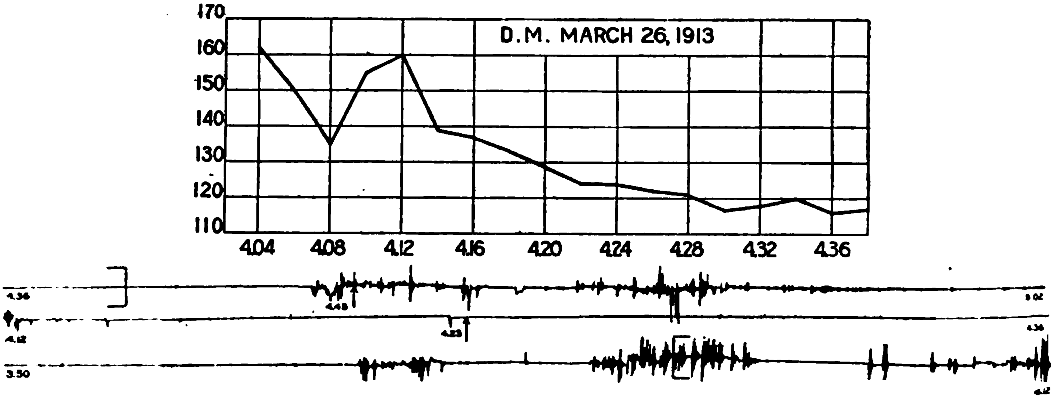

FIG. 27. Pulse-rate and kymograph curves for D. M., March 26, 1913.

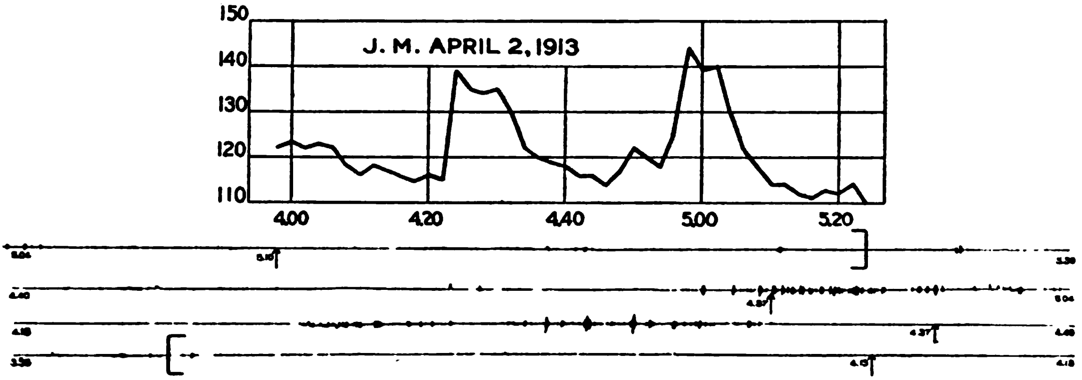

FIG. 28. Pulse-rate and kymograph curves for J. M., April 2, 1913.

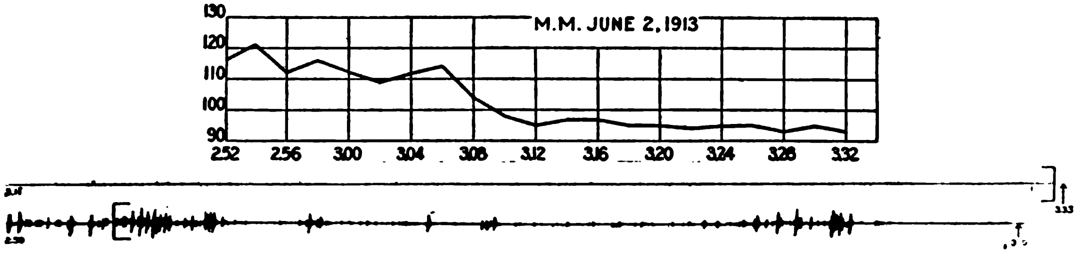

FIG. 29. Pulse-rate and kymograph curves for M. M., June 2, 1913.

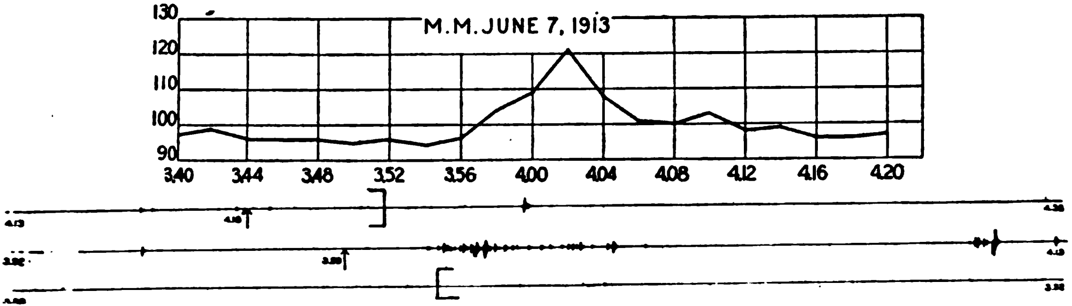

FIG. 30. Pulse-rate and kymograph curves for M. M., June 7, 1913. 3h 40m p. m. to 4h 20m p. m.

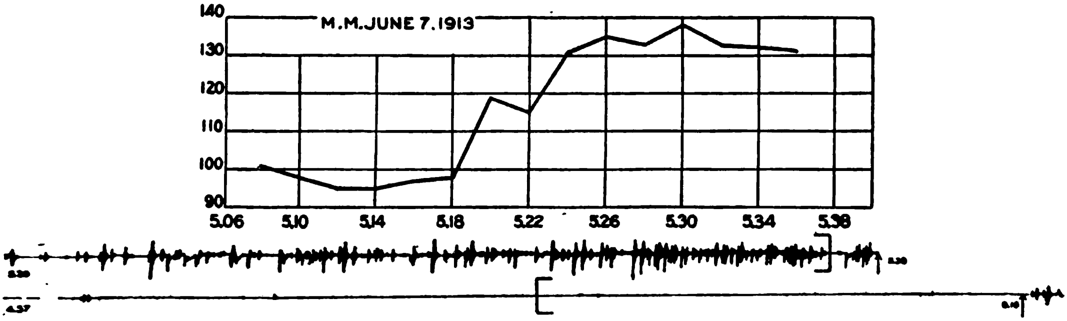

FIG. 31. Pulse-rate and kymograph curves for M. M., June 7, 1913. 5h 8m p. m. to 5h 36m p. m.

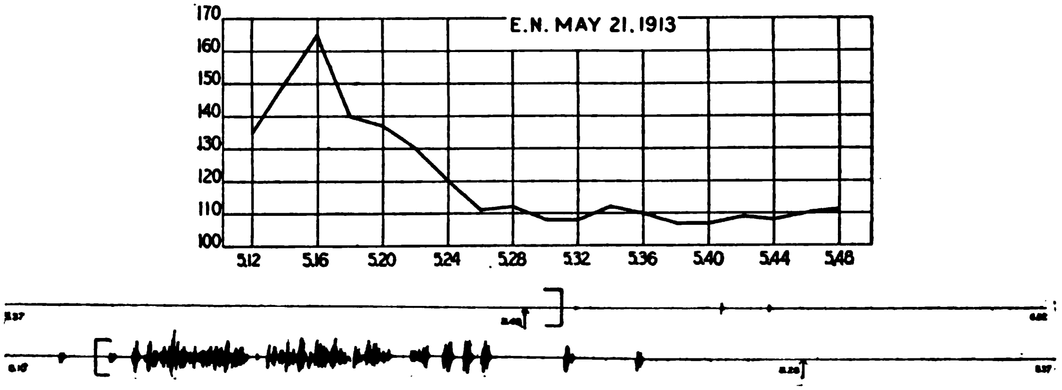

FIG. 32. Pulse-rate and kymograph curves for E. N., May 21, 1913.

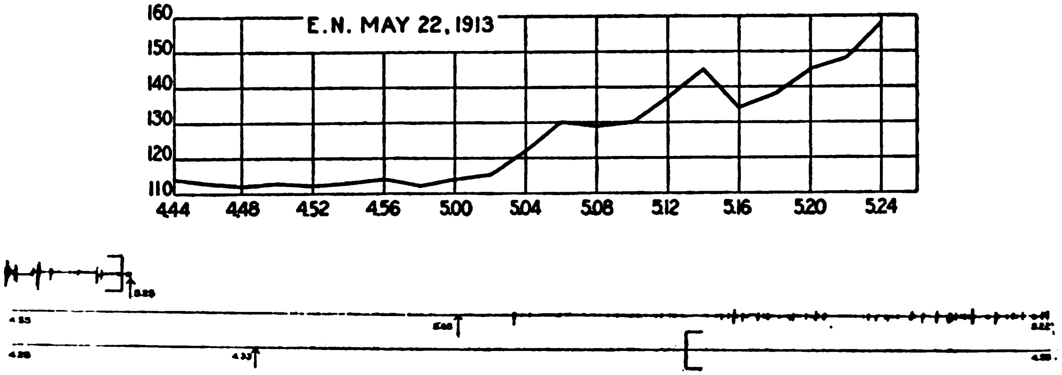

FIG. 33. Pulse-rate and kymograph curves for E. N., May 22, 1913.

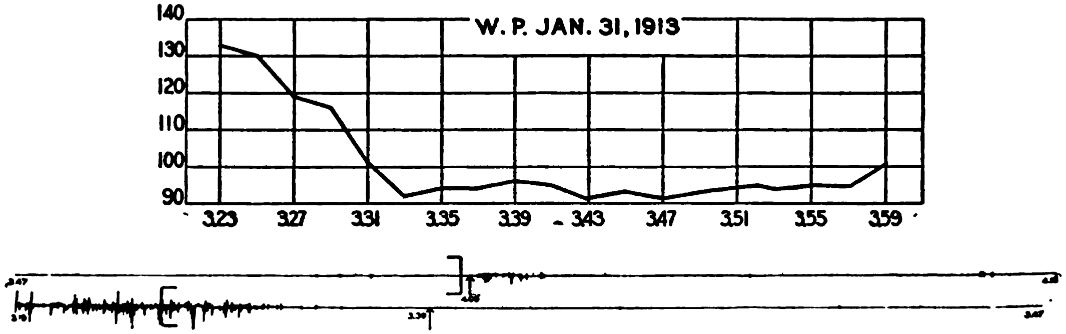

FIG. 34. Pulse-rate and kymograph curves for W. P., January 31, 1913.

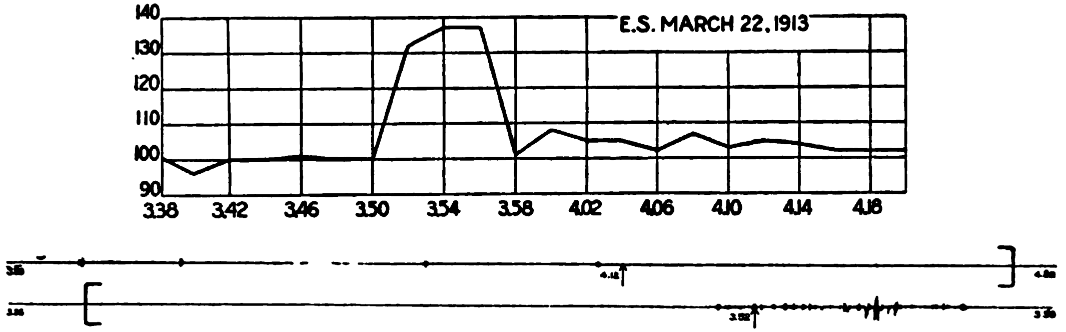

FIG. 35. Pulse-rate and kymograph curves for E. S., March 22, 1913.

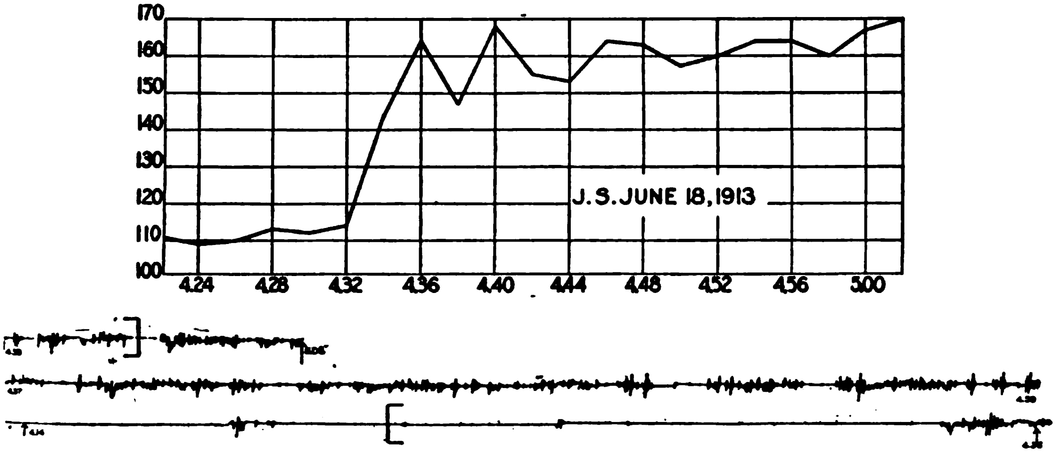

FIG. 36. Pulse-rate and kymograph curves for J. S., June 18, 1913.

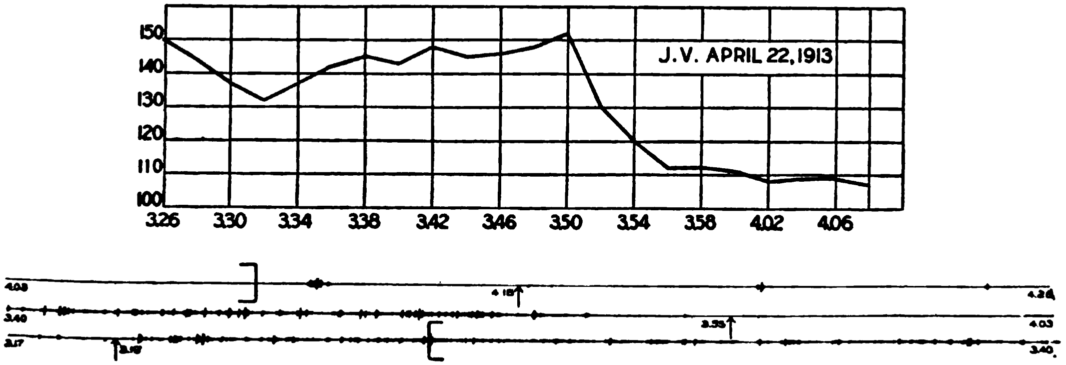

FIG. 37. Pulse-rate and kymograph curves for J. V., April 22, 1913.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE AT DIFFERENT AGES WITH THE SAME INFANT.

The extreme sensitivity of the pulse-rate to major changes in muscular activity has already been shown, but it is also important to note whether or not this sensitivity altered materially with increasing age. With one of the infants, J. V., we were able to make observations when she was 3½ months old, with a body-weight of 1.9 kilograms, and again when she was 7½ months old, with a body-weight of 3.3 kilograms. The curves obtained on January 25 and on May 27 are therefore compared in figure 38.

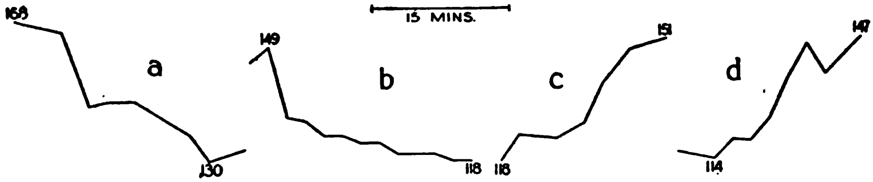

FIG. 38. Pulse-rate curves with J. V.

a. January 25, 1.9 kilograms, 3½ months, awake and crying vigorously, restless, quiet (asleep).
b. May 27, 3.3 kilograms, 7½ months, moving and grumbling, then quiet.
c. January 25, 1.9 kilograms, 3½ months, quiet (asleep), moved, cried, restless, cried.
d. May 27, 3.3 kilograms, 7½ months, quiet, moving, moving and grumbling.

In the period covered by the first curve (*a*) for January 25, *i. e.*, from 3^h 35^m p. m. to 4^h p. m., the infant was at first awake and restless, then quieted down until she fell asleep. The pulse-rate fell from 168 to 130 per minute during this period. The second curve for this day (*c*) shows a change in the pulse-rate from 118 at 4^h 18^m p. m., when the infant was quietly sleeping, to 151 at 4^h 36^m p. m., when she was awake, restless, and crying. In the first instance the fall in the pulse-rate of 38 beats required 25 minutes; in the second instance the rise in the pulse-rate of 33 beats took place in 18 minutes.

On May 27, the records (curve *b*) show that the pulse-rate fell from 149 at 3^h 14^m p. m., when the child was moving, to a minimum of 118 at 3^h 36^m p. m., when it was quiet, or 31 beats in 22 minutes. The second record for this day (curve *d*) shows a rise in the pulse-rate when the infant woke up and cried from 114 at 5^h 06^m p. m. to 147 at 5^h 22^m p. m., or an increase of 33 beats in 16 minutes.

Comparisons of this kind are always complicated by the possible variation in the intensity of the activity, although in the instances selected the external activity seemed to be essentially the same under the various conditions. There was no evidence of greater sensitiveness in the later observations, but there was a distinct tendency for the minimum pulse-rate at the age of 7½ months to be somewhat lower than at the age of 3½ months.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE WITH INFANTS OF THE SAME WEIGHT BUT DIFFERENT AGES.

In order to compare the effect of changes in activity on the pulse-rate of infants of the same weight but of different ages, a number of pulse curves are given in figures 39 and 40, these being grouped according to weight. These curves, like those previously shown, indicate the rapid reaction of the pulse-rate with the change in activity, the reaction being at times so rapid that we may reasonably question the accuracy of the record. The evidence given in these curves seems on the whole to indicate that the rapidity of the return to normal after crying and the increase when the infant waked up and cried are essentially the same with all of the infants, irrespective of age. This evidence does not agree with the results obtained in the earlier observations which were

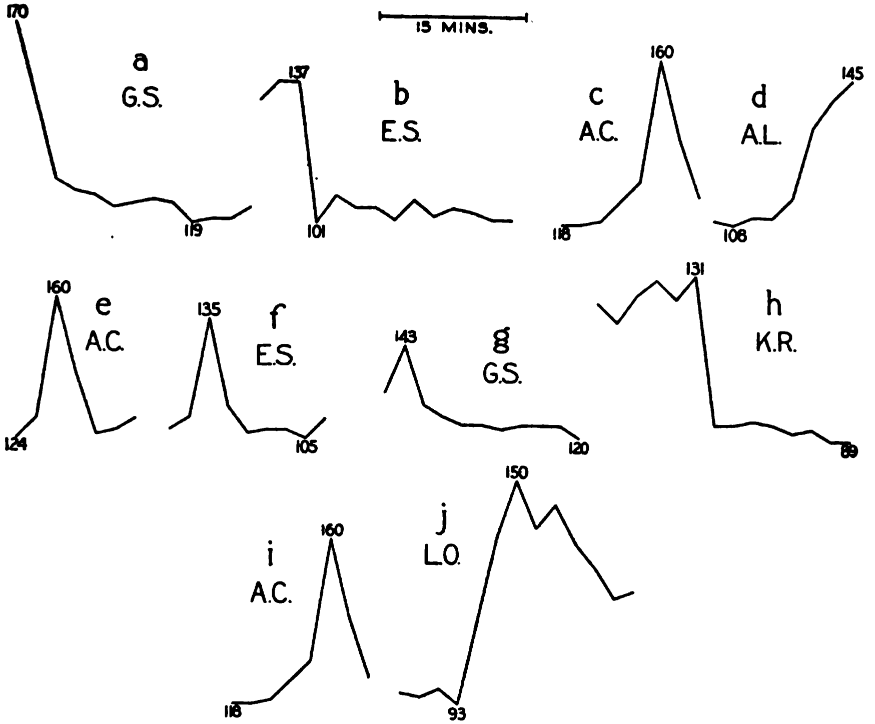

FIG. 39. Pulse-rate curves with infants of like weight but of different ages.

a and *b*. G. S., February 19, 3.3 kilograms, 2½ months, crying and moving, then quiet; E. S., March 22, 3.0 kilograms, 5 months, moved and cried, moving, then quiet.

c and *d*. A. C., March 19, 3.0 kilograms, 1½ months, quiet, moved, cried lustily, crying, quiet; A. L., June 16, 3.1 kilograms, 3½ months, quiet, then moving and crying.

e and *f*. A. C., March 19, 3.0 kilograms, 1½ months, moved, cried lustily, crying, then quiet; E. S., March 21, 3.0 kilograms, 5 months, quiet, moved, moving and crying, then quiet.

g and *h*. G. S., February 14, 3.2 kilograms, 2½ months, moved and cried, restless, then quiet (asleep?); K. R., April 5, 3.1 kilograms, 4 months, moving and crying lustily, moving and crying, then quiet.

i and *j*. A. C., March 19, 3.0 kilograms, 1½ months, quiet, moved, cried lustily, crying, quiet; L. O., February 28, 3.1 kilograms, 6 months, quiet, moved, moving and crying, moving a little.

made under less favorable circumstances. Obviously the curves given in figures 39 and 40 can not be directly compared with the long curves obtained in the hospital wards, since the former were secured under the absolutely uniform conditions obtaining in the respiration chamber and in relatively short experiments.

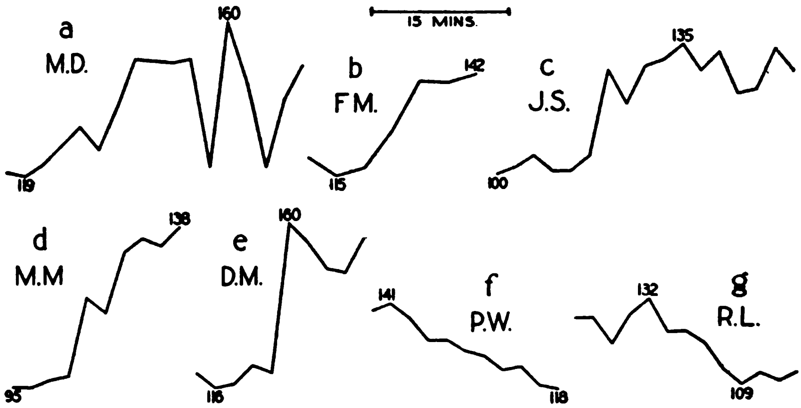

FIG. 40. Pulse-rate curves with infants of like weight, but of different ages.

a, *b*, and *c*. M. D., March 14, 4.0 kilograms, 3 weeks, quiet, then moved, crying and moving, quiet, moving, quiet, moving; F. M., January 22, 3.6 kilograms, 4 months, quiet, restless, restless and crying; J. S., June 11, 4.1 kilograms, 5½ months, moving slightly, fairly quiet then moved, moving and crying.

d and *e*. M. M., June 7, 5. 4 kilograms, 4½ months, quiet, moving, moving and grumbling, moving and crying; D. M., March 26, 5.2 kilograms, 11 months, quiet, moving and crying, moving, moving and crying.

f and *g*. P. W., April 1, 7.1 kilograms, 7 months, moving and grumbling, then quiet; R. L., May 16, 7.3 kilograms, 9 months, moving, then quiet.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE WITH INFANTS OF THE SAME AGE BUT WITH DIFFEERNT BODY-WEIGHTS.

Though the undeveloped, atrophic infants have a different reaction of the pulse-rate to variations in muscular activity from those found with normal infants, some of our data may still be used to throw light upon the question of the differences in the reaction with different body-weights. Curves have been plotted showing the changes in the pulse-rate accompanying changes in body-activity from quiet to crying, or the reverse, with a number of infants of the same age but with different body-weight; these are given in figures 41 and 42.

In only one of the comparisons is there a marked difference. The infants L. O. (curve *e*, figure 42) and J. S., (curve *f*, figure 42), with body-weights of 3.3 kilograms and 4.6 kilograms respectively, when compared with P. W. (curve *g*, figure 42) with a body-weight of 7.1 kilograms, show apparently a greater rapidity in the return to the normal than does the heavier infant. Little can be inferred from the other comparisons.

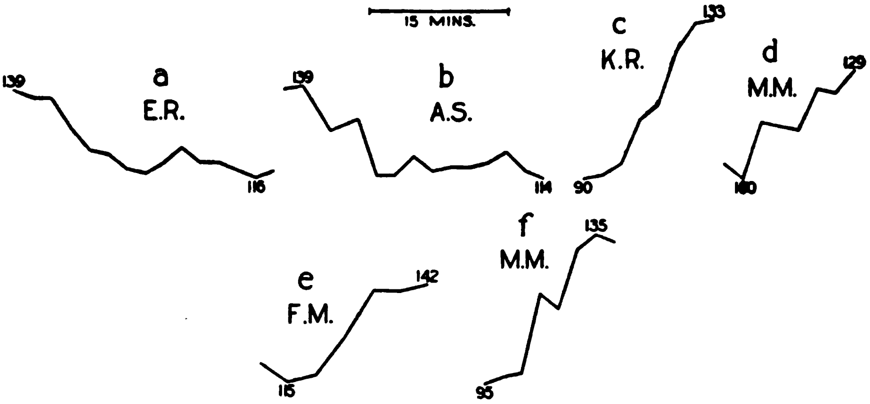

FIG. 41. Pulse-rate curves with infants of like age but of different weights.

a and *b*. E. R., April 14, 3 months, 4.5 kilograms, moving, then quiet, slight movements, quiet; A. S., April 1, 3 months, 6.0 kilograms, moving and grumbling, alternately quiet and moving, then quiet.

c and *d*. K. R., April 5, 4 months, 3.1 kilograms, quiet, moving and grumbling, moving and crying, moving and crying lustily; M. M., June 2, 4½ months, 5.4 kilograms, quiet, moving and crying, moving and grumbling, moving and crying.

e and *f*. F. M., January 22, 4 months, 3.6 kilograms, quiet, restless, restless and crying; M. M., June 7, 4½ months, 5.4 kilograms, quiet, moving, moving and grumbling.

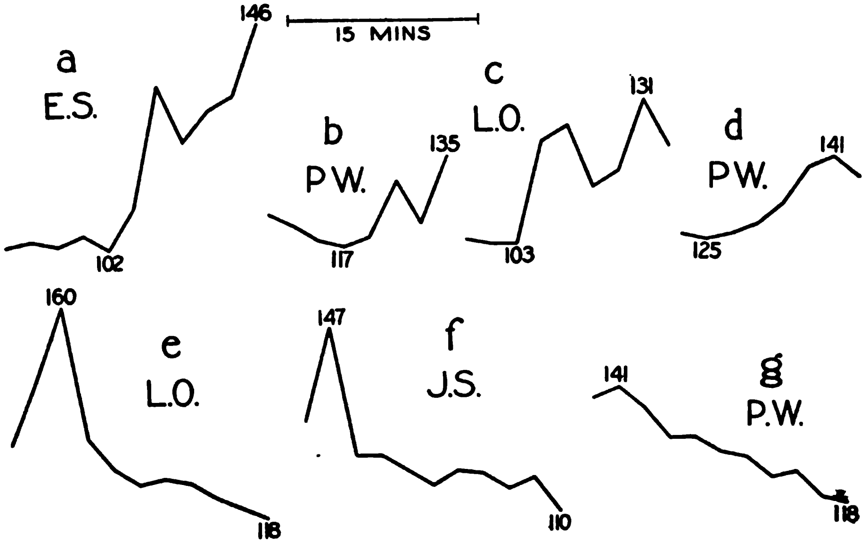

FIG. 42. Pulse-rate curves with infants of like age but of different weights.

a and *b*. E. S., March 21, 5 months, 3.0 kilograms, quiet, then crying and coughing, crying, moving, crying; P. W., April 3, 7 months, 7.1 kilograms, quiet, then moved, crying and moving, quiet, crying.

c and *d*. L. O., March 7, 6 months, 3.3 kilograms, quiet, then moved and turned over, moving: P. W., April 1, 7 months, 7.1 kilograms, quiet, moved, moving and grumbling.

e, *f*, and *g*. L. O., March 12, 6 months, 3.3 kilograms, moving and grumbling, coughed, then quiet; J. S., June 26, 6 months, 4.6 kilograms, moving and crying, then became quiet; P. W., April 1, 7 months, 7.1 kilograms, moving and grumbling, then quiet.

RELATIONSHIPS OF THE MUSCULAR ACTIVITY, PULSE-RATE, AND METABOLISM.

It has been a fundamental principle in all of our previous experimenting, with both adults and animals, that only periods of complete muscular repose should be used for comparison in studying the metabolism. The observations made with infants were also based upon this principle, the index used being the graphic records obtained with the mechanical registering device previously described. While for the major purposes of this publication, quiet periods were sought and the metabolism during periods of restlessness was only incidentally studied, we obviously unintentionally secured a large number of periods of more or less muscular activity. The relationships for the various muscular activities of the infant, the pulse-rate, and the total metabolism may therefore be readily discussed. To this end, a number of kymograph curves are reproduced in figures 43 to 48, showing the muscular activity of several infants.

From a consideration of the mechanical principles of the swinging crib, it can be seen that the heaviest and strongest infants would produce the greatest amplitude of vibration of the crib, this vibration being, in turn, transmitted through the writing point of the tambour to the kymograph. While it would be useless to compare the muscular activity of two infants by comparing the excursions of the writing point on the kymograph, nevertheless a general impression of the activity and strength of an infant considered as a living mass of tissue may be obtained by an inspection of these curves.

Accompanying the curves are tables giving the simultaneous records of the pulse-rate and the metabolism as computed on the basis of the total heat output per 24 hours. An estimate of the activity is also given in this table, using the basis of classification previously explained in table 23. For convenience in referring to these estimates, the key to the classification is given again here, being as follows:

I. Very quiet, probably asleep.
II. Slight movements, few in number.
III. Some activity, but generally quiet.
IV. Moderately active.
V. Distinctly active.
VI. Very active, most or all of the time.

A comparison of the curves with this estimated activity will serve to illustrate the method of estimation used in previous tables.

Observation with J. V., February 27, 1913.

The kymograph curve given in figure 43 was obtained with J. V. on February 27, 1913. This infant was very small and weak, weighing only 2.45 kilograms. She was restless throughout the observation and no period can be classified as activity I. As is usual with many of the observations, the preliminary period, which began at $3^h\ 6^m$ p. m., was characterized by considerable activity. At $3^h\ 34^m$ p. m. there was an ill-advised attempt to begin a new period, notwithstanding the fact that considerable muscular activity immediately preceded the beginning of the period. Up to 4^h 12^m p. m., there was no approach to a condition of repose, but the period from 4^h 12^m p. m. to 4^h 42^m p. m. was the quietest period of the observation. The activity about 4^h 41^m p. m. was taken as indicating that the infant was waking up; as this would naturally be accompanied by considerable activity, a new period was begun. In the last period, that from 5^h 8^m p. m. to 5^h 38^m p. m., the curve is reasonably constant, the regularity of the line being broken by five or six movements. As a rule, perfectly smooth lines could rarely be obtained with this infant.

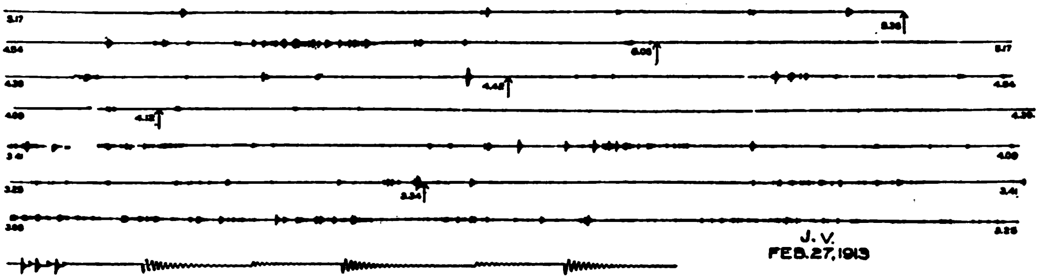

FIG. 43. Kymograph curve for J. V., February 27, 1913.

An examination of the estimated muscular activity given in table 24 shows that while it varied from III to VI, the estimates usually followed quite closely the total heat output. Thus, the two periods characterized as III represent 238 and 233 calories per 24 hours respectively, the two periods marked V correspond to 259 and 254 calories per 24 hours, and the preliminary period, which shows the most activity (VI), corresponds to 281 calories per 24 hours. The fluctuations in the pulse-rate are not very great in this particular observation, the minimum being 135 and the maximum 144; in general they follow the muscular activity and the total heat-production.

TABLE 24.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with J. V., February 27, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
3^h 06^m p.m. to	3^h 34^m p.m.*	281	143	VI
3 34	4 12	259	144	V
4 12	4 42	238	135	III
4 42	5 08	254	141	V
5 08	5 38	233	136	III

*Preliminary period.

A record of the sensitivity test is shown at the bottom of the kymograph curve, and the amplitude of the excursion and the regularity of the vibration vouch for the sensitiveness of the apparatus at that time.

Observation with J. V., April 22, 1913.

Inasmuch as the longest series of experiments with any infant was that made with J. V., and this infant was very small and weak, a second curve is shown, which was obtained on April 22, 1913 (see figure 44). The body-weight at this time was 2.93 kilograms. But one period can be characterized as activity II, *i. e.*, that between 3^h 55^m p. m. and 4^h 15^m p. m. The difficulties incidental to differentiating sharply between the several classifications of activity may here be pointed out, in that during the period from 4^h 41^m p. m. to 5^h 9^m p. m., in which the activity is characterized as III, the heat-production was actually a little less than that in the period between 3^h 55^m p. m. and 4^h 15^m p. m., in which the activity was classified as II, while the pulse-rate was exactly the same (see table 25). On the other hand, in the preliminary and first periods, with the activity characterized as V and VI respectively, both the pulse-rate and the heat-production were considerably higher than in the other periods. Furthermore, in comparing these two periods with each other, we see that in the preliminary period when the activity was V and the pulse-rate 136, the heat-production was a little higher than that for the first experimental period, notwithstanding the fact that both the pulse-rate and the activity were higher in the latter period.

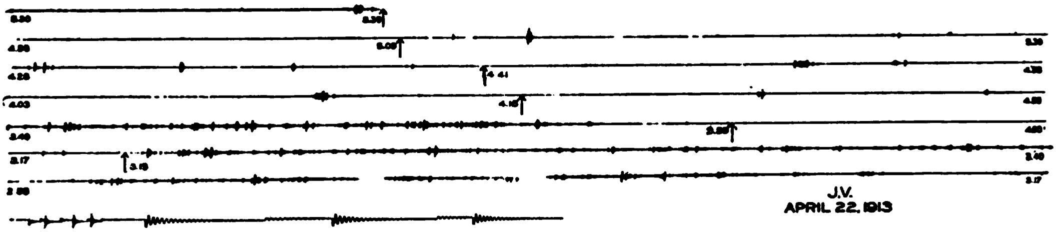

Fig. 44. Kymograph curve for J. V., April 22, 1913.

Table 25.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with J. V., April 22, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
2^h 55^m p.m. to 3^h 19^m p.m.*	329	136	V
3 19 3 55	310	140	VI
3 55 4 15	233	110	II
4 15 4 41	247	115	III
4 41 5 09	218	110	III
5 09 5 39	235	114	III

*Preliminary period.

Throughout this whole monograph, it is important to note that the use of data obtained in the preliminary periods may lead to error, since the amount of carbon dioxide residual in the chamber may be somewhat less at the end of the period than at the start and the temperature conditions may not be ideal; hence the determinations as a whole may be less accurate than those of the subsequent periods. Nevertheless, it is interesting to note in this curve the occasional lack of agreement between the muscular activity record, the pulse-rate, and the total heat-production. As a possible explanation of this, we may cite not only the opportunity for error in the determination of the gaseous exchange in a preliminary period, but the fact that the pulse-rates, particularly when the heart is beating rapidly, are difficult to count without photographic registration. Finally, there may always be a difference of opinion regarding the interpretation of the degree of activity shown by the curves. It is quite possible that the attempt to classify the activity under six heads is a refinement which the method will not warrant; unquestionably much less lack of agreement would be found if but four or even three classifications were used.

Observation with A. L., June 28, 1913.

The curve in figure 45 gives a record of the muscular activity during an observation made with A. L. This infant, who had at the time a body-weight of 3.15 kilograms, was evidently very active and much more vigorous than J. V., as may be seen by the frequency and the amplitude of the vibrations of the pointer on the kymograph. The activities ranged from II to VI, the quietest part of the curve being that between $3^h\ 30^m$ p. m. and $3^h\ 47^m$ p. m., only two small movements near the end breaking the continuity of the line which otherwise would have been characterized as I. Much greater variations in the pulse-rate are to be found with this infant than with J. V., the records ranging from 101 to 137 per minute (see table 26). The minimum pulse-rate was obtained in the period from $3^h\ 30^m$ p. m. to $3^h\ 47^m$ p. m., with an activity of II and a heat-production of 247 calories per 24 hours. In the preliminary period, when the activity was V, the pulse-rate was 118 and the heat-production 343 calories per 24 hours; the last two periods also show a high pulse-rate and heat-production, with an activity of VI. Here again there is general uniformity between activity, pulse-rate, and total heat-production. Although

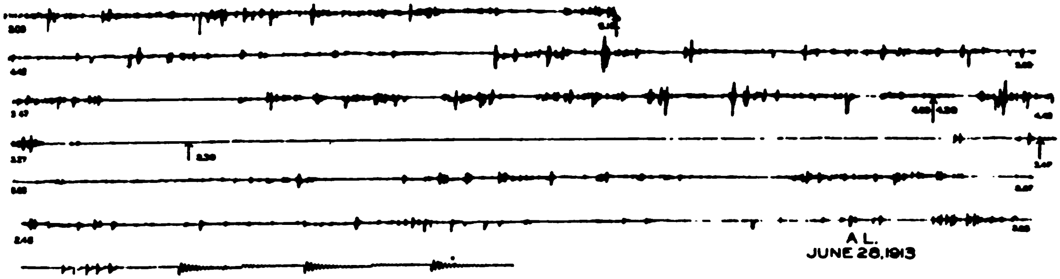

FIG. 45. Kymograph curve for A. L., June 28, 1913.

TABLE 26.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with A. L., June 28, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
$2^h\ 48^m$ p.m. to $3^h\ 30^m$ p.m.*	343	118	V
3 30 3 47	247	101	II
3 47 4 09	379	125	VI
4 39 5 15	374	137	VI

*Preliminary period.

the body-weight of A. L. was but little more than that of J. V., the kymograph curve for the former showed a distinctly greater amplitude and more frequency of movement and the metabolism was also greater. This demonstrates in an interesting manner the fact that A. L. was a more vigorous infant than J. V.

Observation with F. M., February 20, 1913.

Another infant, F. M., with a body-weight of 3.86 kilograms, showed unusually persistent activity throughout practically the whole of the observation on February 20, 1913 (see figure 46). The observation began at 3h 18m p. m., but the activity continued throughout two lengthy periods, *i. e.*, until 4h 42m p. m.; two reasonably quiet periods were subsequently obtained, with an activity of III and II respectively. As would be expected, the heat-production during the preliminary and first periods, when the activity was VI, was very large, being 535 calories per 24 hours in the preliminary period and 528 calories per 24 hours in the first experimental period (see table 27). In the period from 4h 42m p. m. to 5h 12m p. m., when the activity was III, the heat-production fell to 346 calories per 24 hours and the previous high pulse-rate of 141 and over dropped to 119. In the last period, that from 5h 12m p. m. to 5h 42m p. m., when the activity was slightly less and characterized as II, the pulse-rate fell but one point and the total heat-production was 334 calories per 24 hours. It will be seen that in this observation, also, the muscular activity, the pulse-rate, and the total katabolism follow almost parallel courses. Inasmuch as this infant was considerably heavier than either J. V. or A. L., the amplitude of the vibration of the pointer and the activity in general can not logically be used as indications of the body condition or strength of the infant except as showing that he should not in any sense be considered as weak.

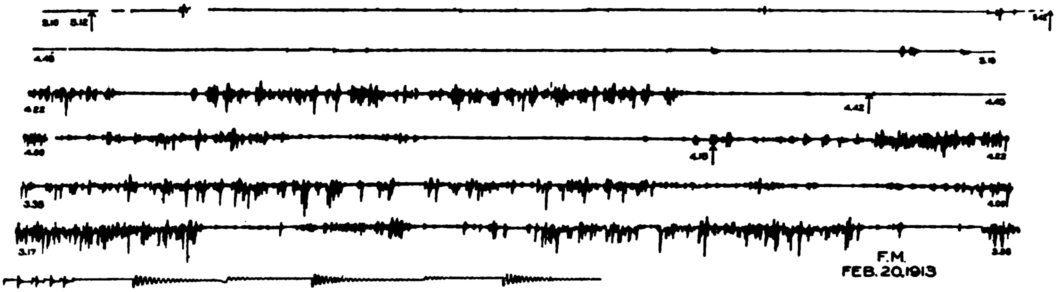

FIG. 46. Kymograph curve for F. M., February 20, 1913.

TABLE 27.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with F. M., February 20, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
3h 18m p.m. to	4h 15m p.m.*	535	147	VI
4 15	4 42	528	141	VI
4 42	5 12	346	119	III
5 12	5 42	334	118	II

*Preliminary period.

Observation with M. M., June 5, 1913.

The kymograph curve for the infant M. M., obtained in the observation on June 5, 1913, has certain striking points, inasmuch as the minimum and maximum activity are very well shown (see figure 47). During the preliminary period from $3^h\ 12^m$ p. m. to $3^h\ 40^m$ p. m., the infant was somewhat restless, quieting down sufficiently about $3^h\ 35^m$ p. m. to justify the beginning of a new period at $3^h\ 40^m$ p. m. As a matter of fact, the infant was so quiet in the next period that the activity can be characterized as I (see table 28).

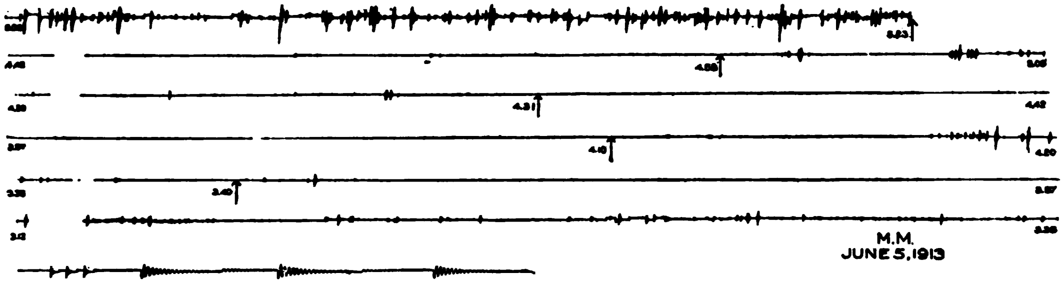

FIG. 47. Kymograph curve for M. M., June 5, 1913.

TABLE 28.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with M. M., June 5, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
$3^h\ 12^m$ p.m. to	$3^h\ 40^m$ p.m.*	365	107	V
3 40	4 10	276	93	I
4 10	4 31	307	96	III
4 31	4 58	288	90	II
4 58	5 23	367	113	VI

*Preliminary period.

The activity in the last period, *i. e.*, that from $4^h\ 58^m$ p. m. to $5^h\ 23^m$ p. m., was sufficiently great to be classified as VI. This curve shows clearly the futility of attempting to graduate by kymograph records the exact degree of the activity and the heat-production, for although the curve appears to indicate that the activity in the last period (from $4^h\ 58^m$ p. m. to $5^h\ 23^m$ p. m.) was much greater than that in the preliminary period from $3^h\ 12^m$ p. m. to $3^h\ 40^m$ p. m., the metabolism is very nearly the same and the pulse-rate is only 6 beats higher in the last period. This also justifies the statement previously made that the measurements obtained in preliminary periods are not sufficiently reliable to admit of extended discussion. The fact that no greater metabolism is shown in the last period than in the preliminary period, although the activity appears to be greater, should therefore be considered as a deduction based upon single measurements in two individual periods, either of which may be liable to error. Furthermore, when comparing the pulse-rates it should be stated that although the average pulse-rate in the preliminary period was 107, the individual counts ranged from 95 to 120, while the pulse-rates in the last period, although the average was 113, actually varied from 93 to 124. Discrepancies such as these serve again to emphasize the fact that only periods of complete muscular repose can logically be used in discussing infant metabolism.

In connection with the classification of the activity in the several periods, it is of interest to compare estimates made independently by two persons several weeks after the first estimate was made. This is done in table 29. The only disagreements after several weeks, during which time several hundred records had been examined, are found in the estimates for the second and fourth periods in distinguishing between classifications I and II. No attempt was made to classify the activities beyond V, any degree of activity beyond this being classed as VI. While one might say that the activity in the last period was two or three times that of the first period, since it is classified as VI, this conclusion is not justifiable, as is shown by the records of the pulse-rate and the metabolism in these two periods.

TABLE 29.—*Comparison of original estimates of activity with later estimates made independently by two individuals.*

(Observation with M. M., June 5, 1913.)

Period.	Pulse-rate.	Estimates of activity.		
		Original.	Later.	
			Reader A.	Reader B.
3h 12m p.m. to 3h 40m p.m.*	107	V	V	V
3 40 4 10	93	I	I	II
4 10 4 31	96	III	III	III
4 31 4 58	90	I	I	II
4 58 5 23	113	VI	VI	VI

*Preliminary period.

Observation with F. K., May 2, 1913.

Another infant, F. K., with a body-weight of 5.68 kilograms, showed activities ranging from I to VI in the kymograph curve for May 2, 1913 (see figure 48). No curve previously given has shown a perfectly smooth line for an entire period, but such a line was obtained in the second experimental period of this observation, *i. e.*, that from 3h 39m p. m. to 4h 1m p. m. Incidentally this indicates how large an amount of experimental work must be done in order to secure a sufficient number of periods with minimum activity for comparison. Indeed, for the fundamental discussion of the comparative metabolism of infants, hardly one-third of our entire series of observations could be utilized.

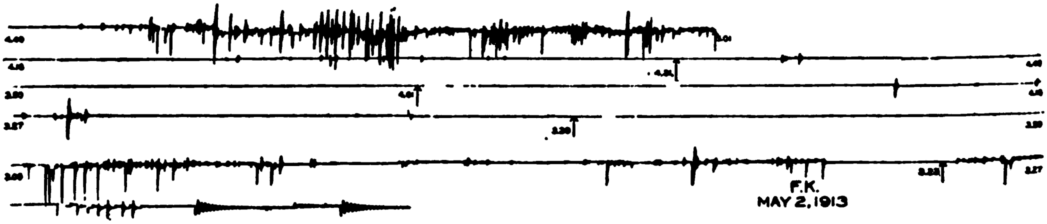

FIG. 48. Kymograph curve for F. K., May 2, 1913.

An interesting comparison of the total metabolism, the pulse-rate, and the records of the activity for this observation is given in table 30. A general uniformity is observed, although the preliminary period (from 3h 1m p. m. to

$3^h 23^m$ p. m.) with an activity of VI has a heat-production and pulse-rate slightly less than the last period (that from $4^h 31^m$ p. m. to $5^h 1^m$ p. m.) with an activity of V. This again illustrates the anomalies observed in comparisons with the results obtained in the preliminary period.

TABLE 30.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with F. K., May 2, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
$3^h 01^m$ p.m. to $3^h 23^m$ p.m.*	526	138	VI
3 23 to 3 39	446	121	IV
3 39 to 4 01	382	109	I
4 01 to 4 31	420	116	III
4 31 to 5 01	535	141	V

*Preliminary period.

Additional comparisons of the muscular activity, the pulse-rate, and the metabolism may be made by reference to the kymograph curves given with the discussion of the relationship between the muscular activity and the pulse-rate.[1] The data regarding the pulse-rates and the metabolism will be found in table 23,[2] which gives the statistics for all of the observations.

SIGNIFICANCE OF THE RELATIONSHIPS.

From the preceding discussion the conclusion may be drawn that only periods of complete muscular repose may be used in comparing the results obtained with different individuals and with the same individuals on different days. The total katabolism of the infant is the resultant of two factors: First, the metabolism due to the internal activity incidental to circulation and respiration and the general muscle tonus of the body, *i. e.*, maintenance metabolism; second, the metabolism due to the external muscular activity, which may vary from slight movements of the hand or fingers to violent movements incidental to severe crying.

The internal muscular activity of the infant may also be affected by the ingestion of food and, as with adults, it may be affected by the general condition of the body, such as in disease or immediately following severe illness. For a short time after feeding, provided essentially the same kind and amount of food is given, it may be assumed that the metabolism due to internal muscular activity is fairly constant[3] with an infant. The effect of the ingestion of food upon the internal muscular activity of the infant is discussed elsewhere in this report,[4] but here we compare primarily the metabolism during complete muscular repose and during various degrees of muscular activity.

The external muscular movements are recorded with considerable fidelity upon the kymograph drum by means of the registering apparatus described, but we have seen that this record does not give a comparative picture of the degree of activity of different infants. Consequently, for comparing the maintenance metabolism only periods in which the external muscular activity is eliminated should be used, since in the last analysis knowledge with regard to internal muscular activity is desired, uncomplicated by the increased metabolism due to external muscular activity. We believe that our evidence justifies us in asserting that we have two admirable indices for securing these ideal conditions of muscular repose for comparison, first, the graphic records obtained with the kymograph, and second, the pulse-rate. For comparing the metabolism of different infants, therefore, only those periods with records of complete muscular repose and with minimum pulse-rate can legitimately be employed.

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[1] See p. 118. [2] See p. 84. [3] Schlossmann, Deutsche med. Wochenschr. 1911, **37**, p. 1635.
[4] See p. 145.

RELATIONSHIP BETWEEN PULSE-RATE AND METABOLISM.

From the general pictures of the kymograph curves and the pulse curves, one may infer that the pulse-rate follows closely the muscular activity. Furthermore, since it has been shown that the relationship between the metabolism and the kymograph curves is comparatively constant, it is reasonable to expect that the pulse-rate will follow the metabolism. That this latter relationship is usually more nearly constant than the relationship between the metabolism and the record of the muscular activity is clearly indicated in a number of observations in which the kymograph record showed a complete absence of extraneous muscular activity, while the pulse records showed fluctuations.

An excellent illustration of this may be seen in the pulse and kymograph curves which were obtained in the observation of February 1, 1913, with the infant L. B. (see figure 49). Thus between 4 p. m. and

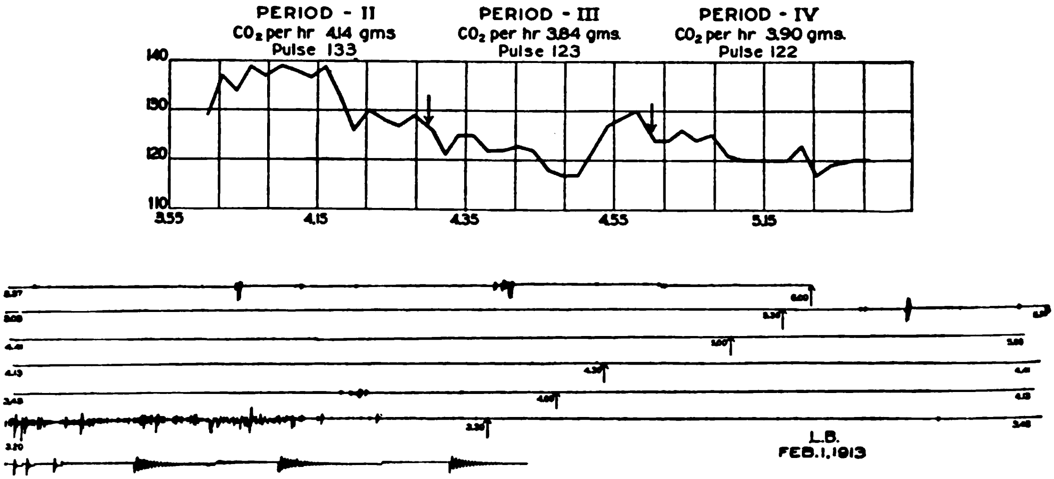

FIG. 49. Pulse-rate and kymograph curves for L. B., February 1, 1913.

$5^h\ 30^m$ p. m., one may assume that the activity was essentially of the grade I, *i. e.*, minimum. Nevertheless the pulse-rate is considerably higher in the period between 4 p. m. and $4^h\ 30^m$ p. m. than in the two following periods, as is shown by the pulse curve and the figures for the pulse-rate per minute. As a matter of fact, the total metabolism is likewise higher in the first period as is evidenced by the carbon-dioxide output per hour which is given on the pulse curve. In this curve, therefore, which excludes the extraneous activity, we find the pulse-rate following very closely the total metabolism. While the kymograph curve did not indicate muscular activity, nevertheless the pulse-rate gave evidence of an increased internal activity.

A comparison of the records obtained for the muscular activity, the pulse-rate, and the metabolism in the observation with A. D. on May 19, 1913, gives further evidence on this important point (see figure 50). In the two periods from $3^h\ 35^m$ p. m. to 4 p. m. and from $4^h\ 31^m$ p. m. to $4^h\ 54^m$ p. m., the muscular activity shown by the kymograph records would be classified as I. The pulse-rate in the first of these periods (period II) was 113 and in the second (period IV) 104. This variation in the pulse-rate is accompanied by a like variation in the carbon-dioxide production, which was 3.02 grams per hour in period II, and 2.66 grams per hour in period IV. Here again the pulse-rate is seen to be a closer index of the total katabolism than is the kymograph record.

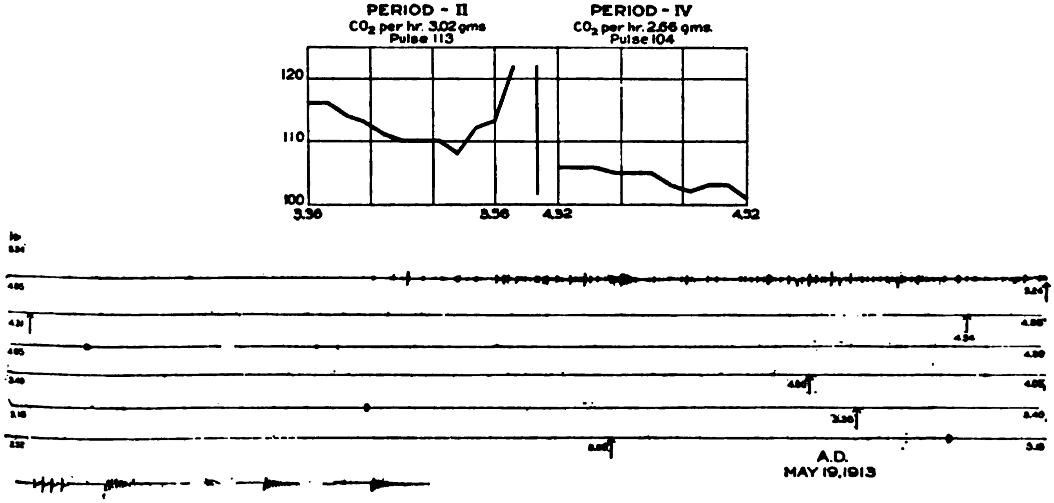

FIG. 50. Pulse-rate and kymograph curves for A. D., May 19, 1913.

Two selected periods which were obtained with the infant J. M. in the observation of April 4, 1913, are compared in figure 51. These periods, both of which had an activity of I, also show the pulse-rate and the carbon dioxide output in harmony, the pulse-rate in period I being 112 as compared with 97 in period VI, with a carbon-dioxide production of 7.08 grams per hour and 6.41 grams per hour respectively.

In this instance the kymograph record indicates a slightly greater activity in period I (from 3h 4m p. m. to 3h 29m p. m.) than in period VI (from 5h 10m p. m. to 5h 26m p. m.), which may account for at least a part of the increase in the metabolism.

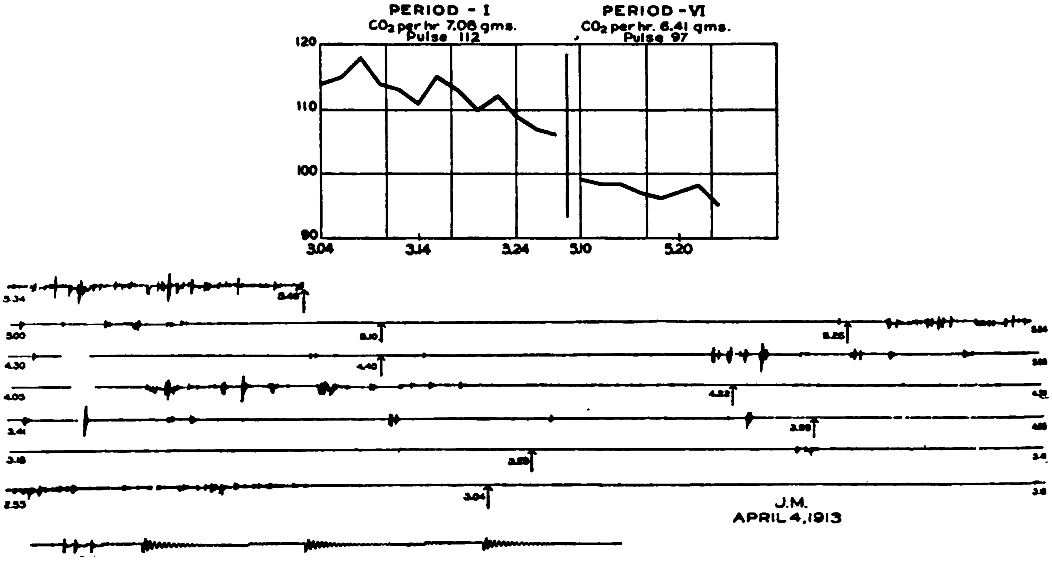

FIG. 51. Pulse-rate and kymograph curves for J. M., April 4, 1913.

With the infant E. N., three periods with an activity of I were secured in sequence on May 26, 1913 (see figure 52). The pulse-rate in the period I from 3h 21m p. m. to 3h 41m p. m. was 104 and the carbon-

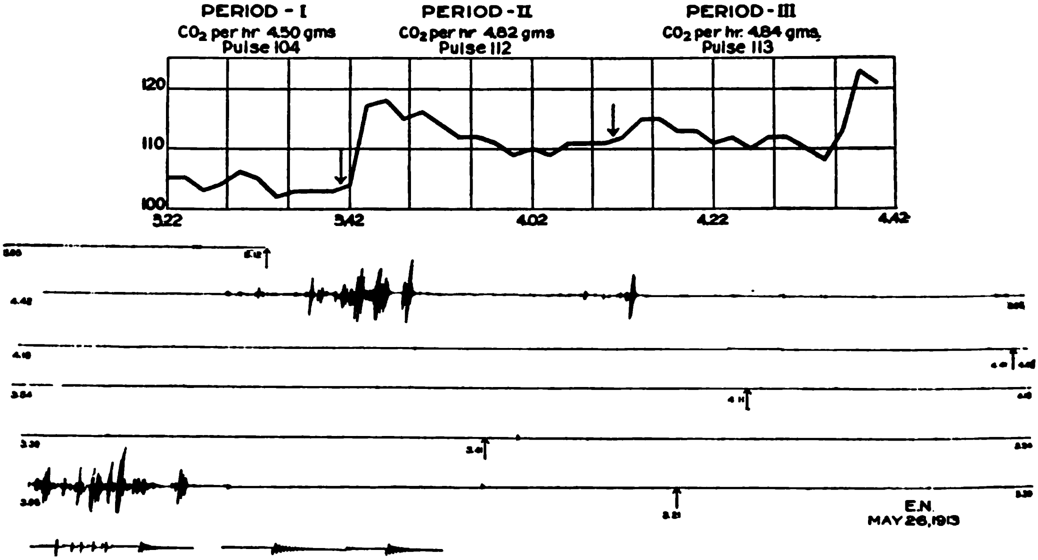

FIG. 52. Pulse-rate and kymograph curves for E. N., May 26, 1913.

dioxide output per hour was 4.50 grams. In the next two periods, the pulse-rates were 112 and 113 respectively and the carbon-dioxide production 4.82 grams and 4.84 grams respectively, showing the usual harmony.

This evidence of the relationship between the pulse-rate and the metabolism, taken in connection with the evidence presented in previous sections of this book, gives an entirely new significance to the pulse-rate, since it may be considered as a very fair index of the metabolism. In other words, an infant having a pulse-rate of 120 at one period of the day and of 150 at another period has unquestionably a greater metabolism in the second period. There is no evidence, however, that a difference in the pulse-rate of any two infants necessarily indicates a proportional difference in the metabolism, even though the infants be of the same weight and age, and the periods of observation of the same length. But it is safe to say that variations in the pulse-rate of an infant indicate a similar change in the metabolism.

It is not to be inferred that we believe that the increase in metabolism noted with increased pulse-rate is due exclusively to the mere mechanical work of circulation, as this is far from our belief. We especially wish to emphasize the fact that we look upon pulse-rate as an index of muscle or general tonus in the body and not as referring solely to the work of the heart muscles.

We may state, therefore, that whatever increases the pulse-rate also increases the katabolism, so that when the pulse-rate is elevated by the muscular activity incidental to restlessness, playfulness, laughing, or crying, or pathologically as in fever, we have every evidence that the katabolism is likewise increased and a larger proportion of food material or body substance is being consumed.

BASAL METABOLISM OF INFANTS STUDIED.

In beginning this research upon infant metabolism, one of the fundamental questions which presented itself to us with special force was as to what may be considered the normal basal metabolism of infants. Consequently we made it our aim to study as many infants as possible and to secure a sufficient number of periods of complete repose on a sufficient number of days to establish beyond reasonable doubt the basal metabolism of each infant. The infants secured for these observations varied sufficiently in age, weight, height, and sex to permit a comparative study of the results as to the constancy or lack of constancy in the metabolism.

SELECTION OF DATA USED FOR COMPARISON.

From the data obtained a table has been compiled which gives the average result of the periods with each infant in which the metabolism was at a minimum (see table 31). The selection of the periods was based upon the records of the pulse-rate and the muscular activity, only such periods being used as showed a normally low pulse-rate and practically no muscular activity, *i. e.,* those characterized as I or II. The figures for the ages and weights are the average ages and weights for the experiments included in the table. The data are arranged according to the increasing weights of the infants. Since with one

TABLE 31.—*Minimum metabolism of infants.*

Subject.	Sex.	Body-weight without clothing.	Height.	Age.	Days included in average.	Periods averaged.	Carbon-dioxide per sq. meter (Meeh) per hour.[1]	Oxygen per sq. meter (Meeh) per hour.
		kilos.	*cm.*	*mos.*			*gm.*	*gm.*
J. V.	F	1.94	47	3½	2	3	12.1	10.8
E. H. S.	M	2.96	51	3½	5	8	11.6	9.6
A. C.	F	2.99	..	1½	3	8	9.7	8.0
E. S.	F	2.99	..	5	3	6	14.0	11.0
A. D.	F	3.16	56	4½	5	15	13.0	10.7
K. R.	M	3.17	56	4	2	4	12.1	10.2
A. L.	F	3.18	53	4	2	2	12.4	10.7
L. O.	M	3.18	..	6	7	12	15.3	12.1
J. B.	M	3.23	..	5	2	4	13.3	10.2
G. S.	M	3.30	..	2½	3	5	12.1	10.0
J. V.	F	3.38	53	8½	3	3	16.7	13.4
F. M.	M	3.65	..	4½	3	5	15.4	13.0
M. D.	M	3.99	..	17 days	2	4	9.2	8.2
L. B.	F	4.04	..	4	3	8	13.2	10.6
E. L.	M	4.15	59	4	1	2	14.0	12.3
W. P.	M	4.31	..	5	2	6	14.6	11.6
J. S.	M	4.41	63	5½	5	7	15.6	11.9
E. R.	M	4.49	55	3	3	5	12.0	11.0
F. B.	M	4.87	60	5½	4	13	15.7	13.1
R. E.	M	5.04	60	4½	3	7	12.2	11.3
D. M.	M	5.18	66	11	2	2	15.0	12.5
D. Q.	M	5.28	62	4½	2	4	11.9	10.1
E. N.	F	5.40	66	6	7	22	13.9	11.7
J. P.	M	5.45	63	7	4	7	15.3	13.0
M. M.	F	5.47	62	4½	3	7	10.6	9.7
J. M.	M	5.63	62	8	2	6	18.2	15.1
M. A.	M	5.67	68	9	4	9	12.9	11.7
F. K.	M	5.71	65	7	6	8	14.2	12.6
L. R. B.	F	5.99	64	4	4	11	11.3	10.4
A. S.	M	6.02	63 ?	3	1	1	10.6	9.5
M. C.	F	6.17	63	4	3	7	11.9	10.1
P. S.	M	6.80	67	12	3	10	14.4	13.3
E. F.	M	7.07	62	3	2	2[2]	10.2	8.7
P. W.	M	7.11	64 ?	7	2	5	14.2	12.2
R. L.	M	7.58	71	8½	5	8	13.9	12.2
E. K.	M	8.03	73	17	1	2	14.2	12.9
H. T.	M	9.33	75 ?	5½	1	1	12.4	9.5
E. G.	M	9.37	74	10	3	5	11.4	11.4

[1] In accordance with the usage of Continental writers, we give these values, although we believe they are peculiarly liable to misunderstanding, and hence their use is unfortunate.

[2] The activity estimated for these two periods was II and III, respectively.

infant, J. V., the studies continued over a period of several months, the average minimum metabolism is given for periods secured at an early age, and again for periods obtained several months later. Various bases of comparison may be used, but in this table the infants have been compared on the basis of the energy transformation in 24 hours.

In employing the data in table 31 for the discussion of the fundamental questions considered, it is necessary to emphasize the fact that the amount of material and the method of its selection justify its use for a basis of comparison. The number of infants, *i. e.*, 37 in all, permits extended comparison and discussion.

TABLE 31—Continued.

Subject.	Heat produced.					Average rectal temperature.[2]	Pulse-rate.
	Per 24 hours.	Per kilogram per 24 hours.	Per square meter per 24 hours.				
			Howland.[1]	Lissauer $10.3\sqrt[3]{W^2}$.	Meeh $11.9\sqrt[3]{W^2}$.		
	cals.	*cals.*	*cals.*	*cals.*	*cals.*	*°C. (°F.)*	
J. V.	164	85	984	1032	882	....	129
E. H. S.	194	65	891	906	783	36.8(98.2)	109
A. C.	163	55	756	759	660	37.2(98.9)	126
E. S.	225	75	1036	1048	911	36.5(97.7)	107
A. D.	229	72	1010	1026	895	36.5(97.7)	114
K. R.	213	67	936	960	829	36.6(97.8)	103
A. L.	226	71	996	1020	876	36.8(98.3)	107
L. O.	260	82	1154	1172	1008	36.9(98.5)	106
J. B.	223	69	978	996	854	36.1(97.0)	95
G. S.	216	65	931	946	818	36.9(98.4)	119
J. V.	297	88	1264	1280	1108	37.3(99.1)	126
F. M.	300	83	1219	1238	1064	37.1(98.8)	118
M. D.	196	49	738	756	656	37.0(98.6)	127
L. B.	272	67	1020	1041	901	36.9(98.5)	124
E. L.	306	74	1128	1152	995	37.2(99.0)	127
W. P.	303	70	1076	1104	962	36.8(98.2)	96
J. S.	319	72	1114	1152	997	36.9(98.5)	111
E. R.	283	63	979	1013	873	37.2(98.9)	116
F. B.	370	77	1211	1257	1082	37.2(98.9)	111
R. E.	324	64	1035	1070	919	37.1(98.7)	114
D. M.	369	71	1152	1188	1034	37.3(99.1)	119
D. Q.	305	57	930	972	846	37.3(90.1)	101
E. N.	353	66	1069	1117	962	37.1(98.7)	111
J. P.	387	70	1152	1207	1039	36.8(98.3)	105
M. M.	285	52	854	891	770	36.8(98.2)	96
J. M.	467	83	1368	1432	1239	37.2(98.9)	112
M. A.	356	63	1037	1085	939	36.9(98.5)	105
F. K.	381	67	1107	1158	1003	37.2(98.9)	109
L. R. B.	331	55	923	973	844	37.2(99.0)	106
A. S.	305	51	840	888	774	37.3(99.1)	113
M. C.	333	54	912	967	837	37.1(98.8)	103
P. S.	453	66	1133	1219	1058	36.8(98.2)	100
E. F.	311	44	756	828	708	37.1(98.8)	111
P. W.	439	62	1061	1147	998	37.1(98.8)	120
R. L.	455	59	1038	1140	991	37.4(99.4)	115
E. K.	497	62	1092	1212	1044	37.7(99.9)	105
H. T.	420	45	816	912	797	37.2(98.9)	101
E. G.	479	51	922	1046	907	37.2(98.9)	106

[1] See p. 22.

[2] During respiration periods.

Furthermore, the data are sufficiently extensive for each subject, as an examination of the table will show that, in all but two instances, at least two periods are used for securing the average value for each infant; in other words, the values were determined in duplicate. In many cases the number of periods for comparison greatly exceeded this; for example, in one instance 22 periods were available for averaging. The values for two infants, A. S. and H. T., are each based upon only one period and unfortunately these two are among the relatively few infants not under weight. We believe, however, that the probable accuracy of these periods is supplemented by a careful examination of other periods with these infants in which the metabolism accompanying the varying degrees of restlessness and activity was measured. Under the circumstances we do not feel justified in excluding these values from the table, although it is to be noted that in all of the subsequent discussion they may readily be omitted without in any way affecting the general inferences drawn from the research.

Obviously no infant lives on a minimum metabolic plane throughout the entire 24 hours; indeed, but a small proportion of the total number of the experimental periods could be utilized for this important comparative study. Nevertheless, since in but two instances was it necessary for us to rely upon the computation of the minimum metabolism of the infant from one experimental period, and in only one other instance were our data limited to those secured in two periods on one day, we believe that we have obtained a reasonably accurate estimate of the minimum metabolism of each infant, which justifies critical study and comparison.

Minimum Extraneous Muscular Activity.

In the previous discussion of basal metabolism,[1] we pointed out that this term is applied to the minimum metabolism of an infant, unaffected by extraneous muscular activity, and that it is probably best secured a number of hours after the last meal, when the infant is lying perfectly quiet, preferably asleep. It should here be emphasized that the discussion of table 31 and the charts in figures 53 to 65 are based upon this minimum basal metabolism.

As the investigation progressed, however, and the intimate relationship between pulse and muscular activity[2] became apparent, we found ourselves compelled to utilize the pulse records intelligently as an important adjunct in determining the minimum metabolism. Any effort to quantify the kymograph curves which were other than straight lines was obviously very difficult, for a break in the straight line caused by a variation of the pointer over 11 mm. might signify one gross movement, while a number of very small breaks with a sum of 20 or 30 mm. need have no such definite mathematical relationship to the heat-production. On the other hand, when the pulse-rate was persistently low, even periods with kymograph records which were not obviously straight lines could logically be used. So extraordinarily sensitive was the tambour and suspended crib system that the slight fluctuation which would be characterized, for example, as activity II, if unaccompanied by an increase in the pulse-rate, showed almost invariably no effect upon the metabolism. In a relatively few instances a kymograph curve that might be classified as III or between II and III was likewise unaccompanied by an increase in the pulse-rate and corresponded to a low metabolism period. While in general, therefore, the results are drawn from periods of absolute repose as indicated by the kymograph records, we have felt perfectly justified in including periods with activity II and rarely III, if they were accompanied by low minimum pulse-rates and a low metabolism. Such a selection was especially fitting, inasmuch as the average minimum metabolism of each infant was sought and the data are nearly always drawn not from a single isolated period, but from many periods, usually obtained on a number of days.

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[1] See p. 30. [2] See p. 118.

Occasionally an extraordinarily low value for the heat-production as computed indirectly was found for a single period. This low value was never included in the periods averaged for the minimum metabolism, as we believed it could be easily traced to an error in weighing the carbon-dioxide absorbers, or to some error in technique pertaining to the individual period. An examination of table 23 will show that these very low values were rare, being found possibly 4 or 5 times during the experimenting of a whole winter. It will be seen, therefore, that care was taken with every infant to secure the minimum value, knowing that ultimately several important comparisons would be made. All the information necessary for the use of investigators in making computations by any other method than those here suggested is given in table 23.[1] The data in this statistical table can be used with confidence, although we have not thought it wise to reject arbitrarily the very low values found in isolated periods. We firmly believe, however, that these were due to some discrepancy which unavoidably crept into the technique and a careful inspection of the data will show that they should not be employed in drawing average values.

MINIMUM INFLUENCE OF FOOD.

In discussing our results, the criticism can be raised that one of the factors outlined in our definition of basal minimum metabolism was not as strictly observed in this study as could be desired, since the infants were rarely in the post-absorptive state, the observations being made for the most part from 1 to 1½ hours after the ingestion of food.

It has clearly been shown in experiments on men and animals that the ingestion of a mixed diet results in an increased metabolism.

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[1] See p. 84.

When isolated nutrients are ingested, the greatest increase has been observed with protein. With fat there is relatively but little, if any, increase. With carbohydrates, while investigators differ as to the quantitative relationships, it has been observed with men in this laboratory that cane sugar and levulose may stimulate the metabolism to a degree comparable with that resulting from the ingestion of an equivalent weight of protein. On the other hand, lactose—the chief carbohydrate in the diet of infants—has a minimum influence upon the metabolism.

This criticism of our experiments has, therefore, considerable theoretical importance, but practically we must consider the fact that the diet of the infant is of such a character as to produce a minimum amount of increase in the metabolism. With infants a large proportion of the protein ingested—some 60 per cent or more—may be stored in the body, and Rubner has shown that this storage does not affect the total metabolism. Since the protein ingested by the infant rarely exceeds 15 per cent of the total energy requirement of the body,[1] it can be seen that we may expect from this nutrient only the minimum influence upon the heat-production of infants. Fat has admittedly but a slight influence, while the predominating carbohydrate—milk sugar or lactose—has likewise only a minimum influence.

On these grounds, therefore, one would conclude that the total nourishment of the infant consists of material which for the most part does not tend to stimulate the metabolism greatly. On the other hand, so keen an observer as Schlossmann[2] states that the effect of the ingestion of food probably persists for some 18 hours. Practically all of the investigators in metabolism have concluded that with adults, unless the diet is abnormally rich in protein, the metabolism reaches the basal line 12 hours after the last meal.

In our studies while it was impracticable to secure the metabolism on all of the infants 18 hours after the last meal, an effort was made to find out the length of time required to obtain the minimum basal metabolism after feeding milk. To this end some five or six infants were studied 1, 2½, 5, 9, 12, 18, and 21 hours after food. The difficulties in securing ideal periods of rest exactly coincident with definite periods of time after the ingestion of food are sufficiently obvious to need no special comment here; it is only necessary to state that our evidence is admittedly not so complete as we should like. A critical examination of the data shows us, however, that on the whole the influence of milk feeding upon the metabolism of infants must be very slight. In certain instances the metabolism during quiet periods immediately after feeding is 5 to 10 per cent higher than 18 to 21 hours after, while in others the metabolism 21 hours afterward, even in periods of complete muscular repose, was slightly greater than immediately after feeding. But the general picture derived from these observations indicates that the ingestion of milk played a very slight rôle, if any, in affecting the heat-production of the infants studied.

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[1] Rubner, Sitzber. K. Preuss. Akad. Wiss., 1911, **20**, pp. 440–457.
[2] Schlossmann, Atrophie u. respiratorischer Stoffwechsel, Kassowitz Festschrift, Berlin, 1912, p. 318.

Recent observations in this laboratory during a 31-day fast showed that, as soon as food was completely withheld, the body storage of glycogen was rapidly drawn upon and a distinct acidosis appeared when it was exhausted. Our experience with diabetics and with normal individuals subsisting upon a carbohydrate-free diet[1] gives evidence that such an acidosis tends to increase the basal metabolism. Additional light has been thrown upon this subject by Schlossmann and Murschhauser[2] who have shown in a recent publication the influence of the withdrawal of food upon the excretion by infants of products of acidosis, particularly acetone, diacetic acid, and β-oxybutyric acid. Even in the first 24 hours of fasting, definite evidence of the excretion of β-oxybutyric acid shows the beginning acidosis. Knowing, as we do, that acidosis strongly tends to increase the metabolism, one sees instantly that a point or a moment when the influence of the previously ingested food ceases and the influence of an oncoming, though slight, acidosis begins, is extremely difficult to foretell, with our present knowledge. It should not be overlooked, however, that Schlossmann and Murschhauser did not find an increased heat-production in these infants showing incipient acidosis although we are inclined to doubt the validity of drawing conclusions regarding so subtle a factor as acidosis from periods with such changes in the degree of repose.

While, therefore, we recognize clearly that the presence of food in the alimentary tract of our infants has distinct theoretical objections, we believe that such influence, if it exist, can play no quantitative rôle in the striking comparisons of the basal metabolism of different infants which are made in the subsequent pages.

NORMALITY OF INFANTS STUDIED.

In carrying out this study of infant metabolism, we found ourselves immediately confronted by the difficulty of determining what is the normal infant. An inspection of the data supplied by Holt,[3] Heubner,[4] Camerer,[5] Gundobin,[6] and Sutils[7] shows noticeable variations in the normal weight of infants of different nationalities—variations that may easily amount in the earlier months to 5 or 8 per cent, even for a carefully selected, healthy, breast-fed infant. Our infants were usually bottle-fed and for the most part were under the normal weight. To show as clearly as possible the variations between the weights of the infants included in this study and the accepted normal weights of infants of similar ages, we give in table 32, first, the age; second, the weights of our infants at the time of observation; and third, the average weight for infants of the ages indicated, these averages being compiled from Holt's table for healthy, American, breast-fed infants. Even with normal infants there are great differences in the birth-weight; we have accordingly computed for this table the weight that would be expected for each of our subjects with a normal rate of growth, taking into consideration variations in birth-weight and using the curve for

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[1] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 134.

[2] Schlossmann and Murschhauser, Biochem. Ztschr., 1913, **56**, p. 396.

[3] Holt, Diseases of infancy and childhood. New York and London, 6th ed., 1911.

[4] Heubner, Lehrbuch Kinderheilkunde, 3d ed., Leipsic, 1911, **1**, p. 7.

[5] Camerer, Der Stoffwechsels des Kindes, Tubingen, 1896.

[6] Gundobin, Die Besonderheiten des Kindesalters, Berlin, 1912.

[7] Sutils, Guide pratique du pesage pendant les deux premières années, Paris, 1889.

TABLE 32.—*Normal and expected body-weight of infants included in these observations.*

Subject.	Sex.	Age.	Height.	Body-weight without clothing.	Normal weight for age.	Expected weight.[1]
		mos.	*cms.*	*kilos.*	*kilos.*	*kilos.*
J. V........	Female	3½	47	1.94	5.90	3.95
E. H. S.....	Male	3½	51	2.96	5.90	5.68
A. C.......	Female	1½	..	2.99	4.30	3.99
E. S........	Female	5	..	2.99	6.82	5.35
A. D.......	Female	4½	56	3.16	6.50	5.46
K. R.......	Male	4	56	3.17	6.25	7.40
A. L........	Female	4	53	3.18	6.25	6.49
L. O........	Male	6	..	3.18	7.27	7.62
J. B........	Male	5	..	3.23	6.82	....
G. S........	Male	2½	..	3.30	5.16	5.40
J. V........	Female	8½	53	3.38	8.28	6.33
F. M.......	Male	4½	..	3.65	6.50	....
M. D.......	Male	17 days	..	3.99	3.60	....
L. B........	Female	4	..	4.04	6.25	6.71
E. L........	Male	4	59	4.15	6.25	....
W. P.......	Male	5	..	4.31	6.82	6.15
J. S........	Male	5½	63	4.41	7.10	8.70
E. R.......	Male	3	55	4.49	5.56	5.11
F. B........	Male	5½	60	4.87	7.10	8.24
R. E.......	Male	4½	60	5.04	6.50	5.37
D. M.......	Male	11	66	5.18	9.20	8.80
D. Q........	Male	4½	62	5.28	6.50	5.60
E. N........	Female	6	66	5.40	7.27	....
J. P........	Male	7	63	5.45	7.73	6.38
M. M......	Female	4½	62	5.47	6.50	6.28
J. M.......	Male	8	62	5.63	8.07	....
M. A.......	Male	9	68	5.67	8.49	8.84
F. K.......	Male	7	65	5.71	7.73	7.87
L. R. B.....	Female	4	64	5.99	6.25	6.93
A. S........	Male	3	63 ?	6.02	5.56	5.91
M. C.......	Female	4	63	6.17	6.25	6.93
P. S........	Male	12	67	6.80	9.55	....
E. F........	Male	3	62	7.07	5.56	6.38
P. W.......	Male	7	64 ?	7.11	7.73	....
R. L.......	Male	8½	71	7.58	8.28	7.15
E. K.......	Male	17	73	8.03	....	....
H. T.......	Male	5½	75 ?	9.33	7.10	....
E. G.......	Male	10	74	9.37	8.75	8.98

[1] Calculated by adding to or subtracting from the normal weight for age the excess or deficiency in weight at birth, assuming normal birth-weight as 3.40 kilograms and that increase in weight after birth is the same as for normal development.

average weight of infants given by Holt.[1] (See table 33.) For example, if the infant weighed 0.5 kilogram more than the average weight at birth and we wished to know what it would have weighed at 5 months had it developed in the usual way, we added 0.5 kilogram to 6.82 kilograms (the average weight for this age as recorded by Holt) and considered 7.32 kilograms the weight that the infant would have weighed had it developed normally. The same procedure was followed if the infant was under weight.

It is clear that relatively few of the infants included in our study can be considered of normal weight, that is, the average weight of healthy infants, as only 8 out of the 37 reported are equal to or exceed the normal weight; one of the infants, H. T., is considerably above the normal weight. It is understood, then, that we are considering for the most part infants that are under weight. Certain of these were in the subnormal temperature stage of infantile atrophy; others were in the repair stage and with normal temperature.

TABLE 33.—*Average weights of American infants (Holt).*

Age.	Weight.	Age.	Weight.
mos.	*kilos.*	*mos.*	*kilos.*
Birth...	3.409	7......	7.727
1.......	3.860	8......	8.070
2.......	4.770	9......	8.390
3.......	5.560	10......	8.750
4.......	6.250	11......	9.200
5.......	6.818	12......	9.545
6.......	7.270		

The term "infantile atrophy" is applied to an emaciated infant with such severe indigestion that it is unable to digest weak mixtures of cow's milk, with no gain in weight, and with a subnormal body-temperature. The convalescent stage of infantile atrophy is that in which the same infant subsequently begins to digest its food and to gain weight, and has a normal temperature. Under-weight infants are those who are 0.5 kilogram or more below the average weight for their respective ages but whose digestion is not so severely deranged as those with infantile atrophy. This group includes all infants not classified as normal, or with infantile atrophy, or in the convalescent stage of infantile atrophy.

RELATIONSHIP BETWEEN BODY-WEIGHT AND METABOLISM.

One of the two factors commonly referred to as exercising a most pronounced influence upon the total metabolism is the body-weight. Charts have therefore been prepared in which comparisons have been made between the body-weights of our infants and the heat-production.

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[1] We recognize that there is no absolutely definite normal weight that can be established for all infants. The charts of growth given by the various authorities are all very similar, their differences being explained by the fact that they often represent infants of different nationalities or of different social and hygienic surroundings. Since the charts usually represent average and not normal infants, it is very difficult to apply the test of normal or abnormal weight to any given infant. Therefore, in comparing the infants used in this investigation, both the average and the estimated weights will be considered. Hereafter we shall use the term "normal weight" as meaning the average weight. The average weights of American infants are given in table 33, which is taken from Holt (*loc. cit.*, p. 17), who made it up from the records of 100 healthy nursing infants and the incomplete weight charts of about 300 other infants.

COMPARISON OF THE BODY-WEIGHT OF INFANTS AND THE TOTAL HEAT-PRODUCTION IN 24 HOURS.

A chart comparing the body-weight of our infants with their total heat-production in 24 hours is given in figure 53.

In general one would expect that a large animal would give forth more heat than a small animal, and an inspection of this chart shows that for the most part those infants with the larger body-weight have a larger heat-production. On the other hand, it will be seen that the values by no means lie in a straight line, possibly the most striking exception being J. M., with a body-weight of 5.6 kilograms and a heat-production of 467 calories. It is clear from this chart, therefore, that while in general the larger infants show the larger heat-production, this is by no means invariably the case, and a definite rule, based solely upon body-weight, can not here be established.[1]

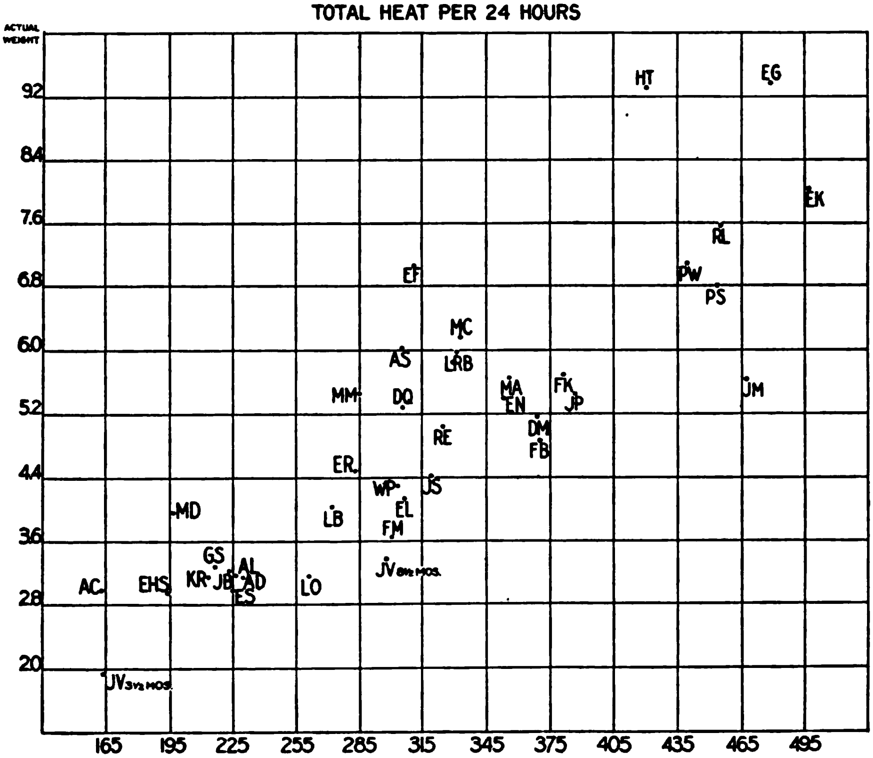

FIG. 53. Chart showing actual body-weight of infants and total heat-production per 24 hours.

It is obvious that the composition of the body must play a considerable rôle. Those tissues most active in the metabolic processes—the muscles and organs of circulation—must have a greater metabolism than the integument, hair, finger nails, etc.; thus, with a larger proportion of active protoplasmic tissue in a body, a greater heat-production would normally be expected. On the other hand, inert adipose tissue, even if it be present in large amounts, would not be expected to contribute materially to the heat-production. Hence it would be logical to assume that heavy, fat infants need not necessarily have a greater total heat-production than infants of the same weight having less fat. Unfortunately, in the discussions of infant metabolism presented heretofore by the various writers, almost no consideration is given to the length[1] of the infant. An infant weighing 8 kilograms, 60 cm. long, has obviously a larger proportion of fatty tissue than an infant of the same weight but 70 cm. long, and on the basis of body-weight alone we should normally expect that the longer, thinner baby, with the smaller amount of fat, would have the larger heat-production.

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[1] By selecting the "normal" infants, a straight line is approximated. Recently determined values on other infants of normal weight indicate considerable regularity in the curve.

As stated in the discussion of table 32 the infants included in our study were, for the most part, under weight. There would thus be a deficiency in fat, and possibly a deficiency in the active protoplasmic tissue, but all of the evidence points to the fact that a large part of the discrepancy in weight must have been due to a deficiency in fat. In considering our infants, it should be borne in mind that the actual body-weight on these or similar charts does not give the slightest indication as to the probable chemical composition of the body, particularly with regard to the proportion of fat or of active protoplasmic tissue. The great lack of uniformity in the total heat-production of 24 hours, when considered on the basis of body-weight, may, therefore, be considered as possibly explained by variations in the chemical composition of the bodies of the different infants, *i. e.*, in the relative proportions of fat and active protoplasmic tissue. Accordingly the chart in figure 53 is chiefly of interest as indicating in this group of infants, as a whole, that there is no definite uniformity between body-weight and total heat-production for 24 hours in infants under uniform conditions as to muscular activity and general repose.

HEAT-PRODUCTION PER KILOGRAM OF BODY-WEIGHT.

A method commonly used for the comparison of individuals of different body-weights is to compute the metabolism on the basis of per kilogram of body-weight. Thus differences in total metabolism ascribable to body-weight alone are eliminated. Accordingly in the chart in figure 54 we have presented the heat-production per kilogram of body-weight per 24 hours for all of our infants. An inspection of these points shows conclusively that there is no regularity in the values for the different infants. The heavy babies, H. T. and E. G., had a low energy transformation per kilogram of body-weight, but two very young infants, A. C. and M. D., had similarly low values, although in general the infants of the smallest body-weight have high values.

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[1] In this connection it should be noted that owing to the stimulating suggestions of Rubner, great emphasis has been laid upon the computed body-surface of infants and its relation to the total metabolism. Aside from the formula of Miwa and Stoeltzner (Zeitschr. f. Biol., 1898, **36**, p. 314) for computing the body-surface of infants, all formulas, including those most extensively used at the present day, disregard completely the length of the infant in computing the body-surface, and the computation, therefore, rests upon a determination of the body-weight—the only measured value introduced into the formula.

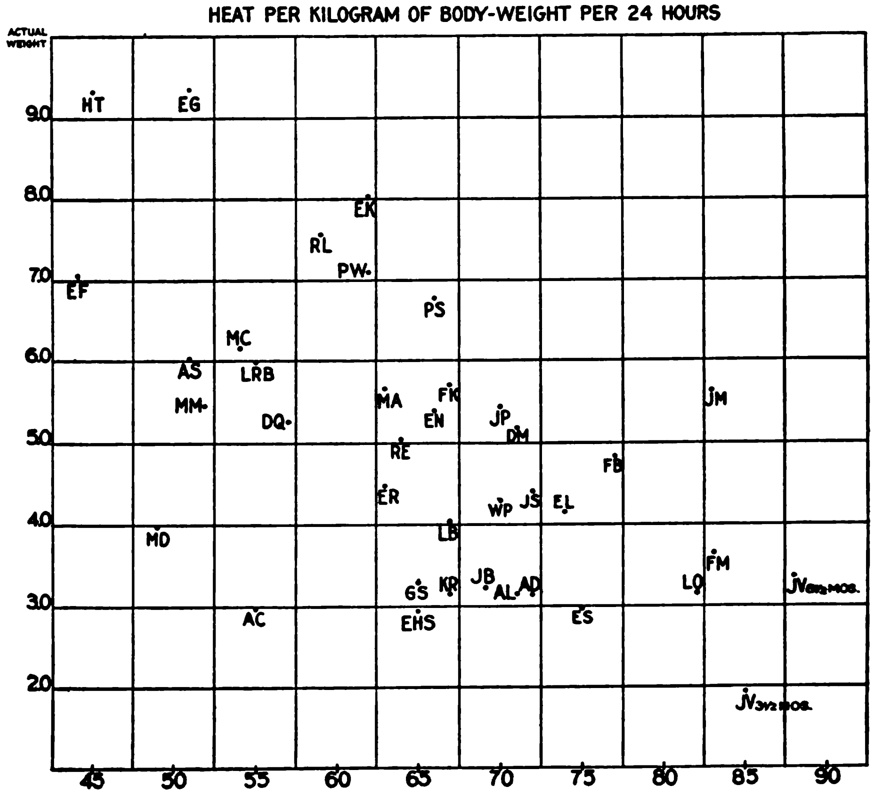

FIG. 54. Chart showing the actual body-weight of infants and the heat-production per kilogram of body-weight per 24 hours.

Thus it is seen that in comparing the metabolism of different infants we have to deal with some factor or factors other than body-weight. Inasmuch as the state of nutrition is not indicated by the records of the body-weight at the time of the observation, it is obviously impossible to discuss the influence of this factor simultaneously with the total body-weight without further data.

COMPARISON OF NORMAL BODY-WEIGHT AND TOTAL HEAT-PRODUCTION IN 24 HOURS.

Since the infants were mostly under weight, a comparison between the metabolism as measured and the normal weight of infants at the same age is justifiable and may prove suggestive in interpreting the results. A chart has therefore been plotted (see figure 55) giving the total heat produced per 24 hours for the different infants and the average body-weight for a normal infant at the age when the metabolism was observed. Here again no special uniformity is seen, although in general those infants with the largest body-weight have the largest heat-production. On the other hand, with infants ranging from 6.3 to 7.3 kilograms, many instances were found when both very low heat-production and high heat-production are noticed.

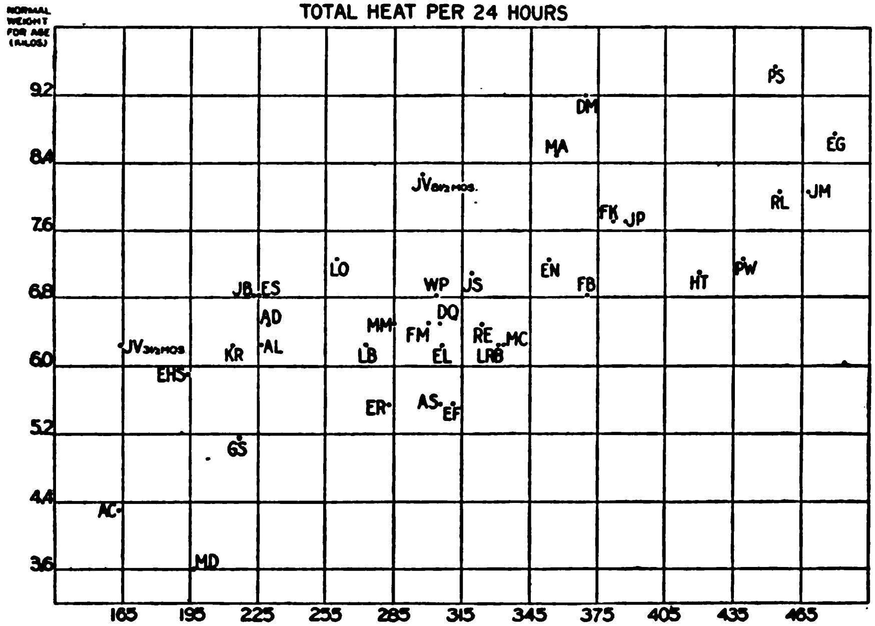

Fig. 55. Chart showing the normal weights for the ages of the infants under observation and the total heat-production per 24 hours.

COMPARISON OF NORMAL BODY-WEIGHT AND HEAT-PRODUCTION PER KILOGRAM OF ACTUAL BODY-WEIGHT.

In an attempt to reduce one factor in the comparison to a common basis, the values for the heat produced have been computed on the basis of per kilogram of body-weight, using the average weight for normal infants of the same age (see figure 56). No greater uniformity is apparent here than in the preceding charts and evidently no correlation can be found between the computed normal body-weight and total heat-production either on the basis of the total heat per 24 hours or the heat per kilogram of body-weight.

COMPARISON OF EXPECTED BODY-WEIGHT AND TOTAL HEAT-PRODUCTION IN 24 HOURS.

The average body-weights of healthy infants used in the foregoing comparisons are based upon the assumption that the infant was of normal weight at birth. Since the birth-weights of many of our infants

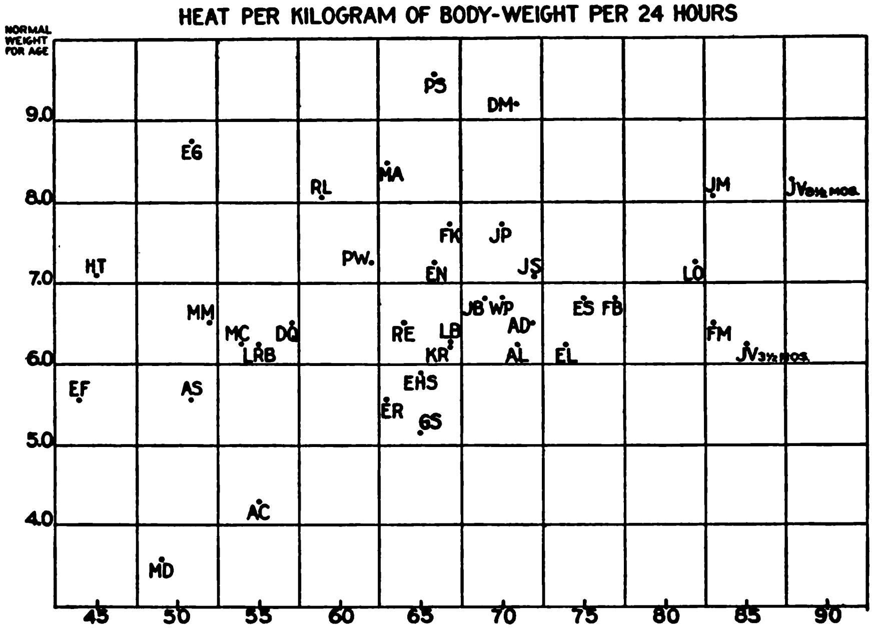

Fig. 56. Chart showing the normal weights for the ages of the infants under observation and the heat-production per kilogram of actual body-weight per 24 hours.

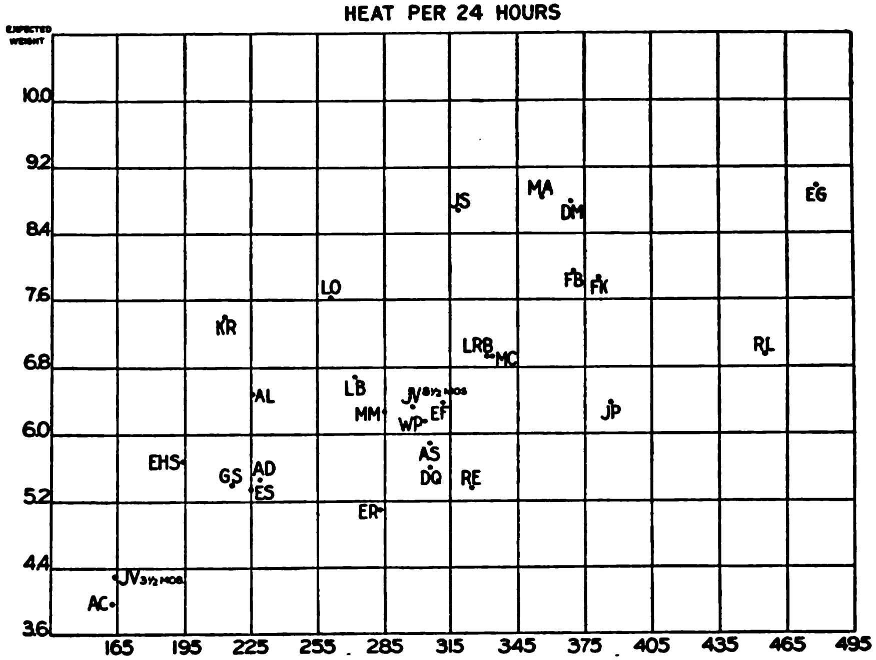

Fig. 57. Chart showing the expected weights for the infants under observation and the total heat-production per 24 hours.

are known to us, we computed the expected weight of our infants as explained on p. 148, thus taking into account any variation from the normal in birth-weight but assuming normal growth. These weights, which are given in the last column of table 32, are compared with the total heat-production in the chart in figure 57. As in all the foregoing comparisons, no regularity is apparent.

COMPARISON OF EXPECTED BODY-WEIGHT AND HEAT-PRODUCTION PER KILOGRAM OF ACTUAL BODY-WEIGHT.

We have plotted in the chart in figure 58 the values for the heat-production per kilogram of actual body-weight for 24 hours for those of our infants whose birth-weight was obtainable. The same absence of any tendency toward regularity in the chart is seen as in the foregoing comparisons. We may therefore conclude that, aside from a slight tendency for the total metabolism to be larger with increasing weight, no regular relationship exists with infants between the total heat-production and the body-weight, regardless of whether the body-weight was actually found, computed from statistics of average values for normal infants, or was the expected body-weight based upon the birth-weight. This lack of correlation is likewise seen when the heat-production per kilogram of body-weight for 24 hours is computed on the various weight bases. It is clear, then, that some factor other than the body-weight influences the heat-production.

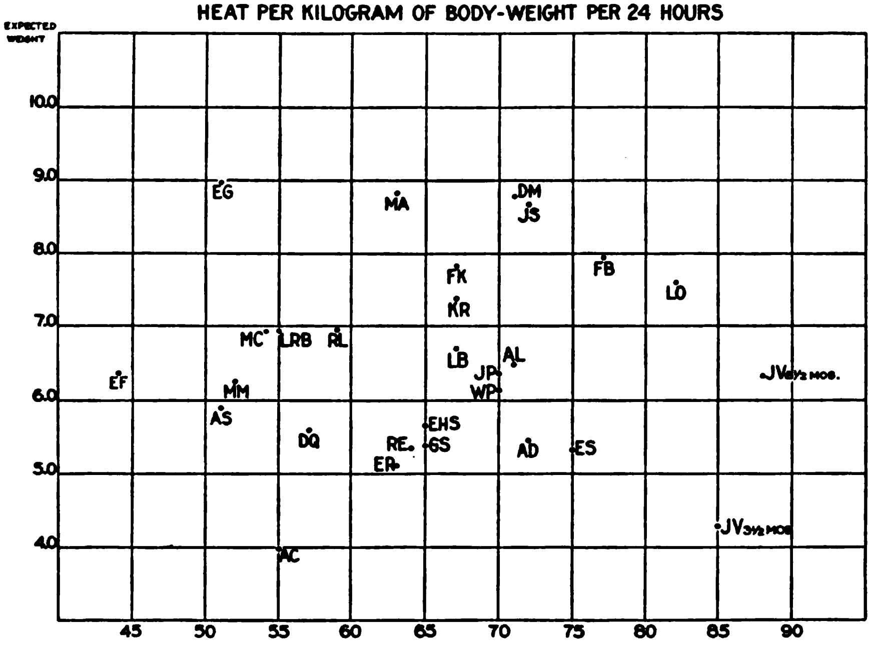

FIG. 58. Chart showing the expected weights for the infants under observation and the heat-production per kilogram of actual body-weight per 24 hours.

COMPARISON OF THE AGE AND HEAT-PRODUCTION PER KILOGRAM OF BODY-WEIGHT.

Since an inspection of the data contained in table 31 appeared to show that the younger infants produced the least heat per 24 hours, it seemed desirable to study the influence of age upon the metabolism. A chart was prepared in which the heat per kilogram per 24 hours is compared with the age at the time of observation, this comparison being given in figure 59. Here again no correlation is indicated between the two factors, infants 4½ months of age showing a heat-production per kilogram of body-weight ranging from 55 to 85 calories per kilogram per 24 hours.

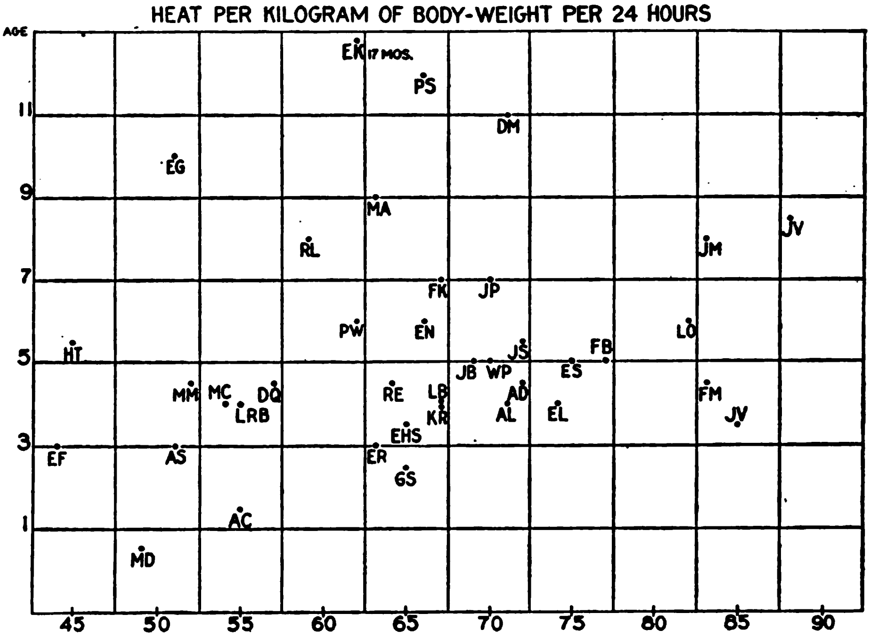

FIG. 59. Chart showing the age of infants and heat-production per kilogram of body-weight per 24 hours.

From these data, therefore, it would appear that neither the weight nor the age shows a uniform relation to the total heat-production or to the heat-production per kilogram of body-weight. In this finding we are completely in accord with all other experimenters in metabolism, since the lack of relationship between body-weight and metabolism is invariably noted. This is particularly the case when two living bodies are compared which vary considerably in weight.

With men, it is true, the metabolism per kilogram of body-weight is considered and commonly used as a reasonably accurate base-line for comparative purposes. Nevertheless the relationship is invariably disturbed when one of the individuals is very fat and the other undernourished, so that although the use of the base-line of per kilogram of body-weight may be justified when comparing individuals of average weight and approximately constant body composition, *i. e.*, with no great differences in the proportion of body-fat and muscular tissue, yet when comparing bodies of widely varying body-weight and body-composition, this basis of comparison can not be considered reliable.

RELATIONSHIP BETWEEN BODY-SURFACE AND METABOLISM.

For many years writers in metabolism have been wont to emphasize the significance of the relationship supposed to exist between the metabolism and the body-surface rather than that between the metabolism and the body-weight. The idea that there is an intimate relationship between body-surface and heat-production was first brought out by Bergmann[1] in 1847. The theory lay dormant for many years, but was finally resuscitated and put forth in a brilliant and highly stimulating manner by Rubner[2] in 1883, together with experimental evidence. Based fundamentally upon Newton's law of cooling, it received great attention from practically all workers in physiology. Startling evidence was brought forward to demonstrate that the heat-production per square meter of body-surface was about 1,000 calories for practically all species of animals, and this lent further support to the hypothesis. In connection with our own researches we naturally expected to find a close relationship between body-surface and total metabolism, particularly in view of the fact that recent observations from foreign laboratories appeared to confirm the validity of Rubner's law. We were therefore greatly surprised on preparing our final figures to find this intimate relationship entirely disturbed.

METHODS USED FOR MEASUREMENT OF BODY-SURFACE.

In order to discuss intelligently the relationship between the metabolism and body-surface, a critical examination of the various methods for determining the body-surface is essential. Using as a basis the relationship between the surface of similar solids which is expressed by the cube-root of the square of the weight, efforts have been made by a number of investigators to compute the body-surface of various animals and individuals from the body-weight.

Meeh[3] found that he could measure the body-surface of men by using the constant 12.312, which, when multiplied by the cube-root of the square of the body-weight in grams, gave the body-surface in square centimeters. Rubner and Heubner,[4] who first applied this formula to the study of the total metabolism of infants, rightly substituted the value 11.9 which was determined by Meeh on the two well-nourished infants under 1 year that he measured.

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[1] Bergmann and Leuckart, Anatomisch-physiol. Uebersicht des Thierreichs. Stuttgart, 1852. p. 272. See also, Bergmann, Wärmeökonomie der Thiere. Göttingen, 1848, p. 9.

[2] Rubner, Zeitschr. f. Biol., 1883, **19**, p. 545.

[3] Meeh. Zeitschr. f. Biol. 1879, **15**, p. 425.

[4] Rubner and Heubner, Zeitschr. f. exp. Pathol. u. Therapie, 1904–1905, **1**, p. 1.

Recognizing the importance of considering the length of the body as well as the circumference of breast and abdomen, Miwa and Stoeltzner,[1] using Meeh's measurements, proposed another formula, in which the length and circumference as well as weight should appear as factors. This formula has not been generally accepted by research workers.

Actual measurements of the body-surface of cadavers have also been used in an attempt to find some mathematical formula expressing the relationship between body-weight and body-surface. Lissauer[2] measured 12 cadavers, 11 of which were under one year, and found that the constant 10.3 should be used in the Meeh formula instead of those previously proposed. It has been maintained by other writers that since many of Lissauer's measurements were made upon thin, poorly nourished, and atrophic infants, they do not give standards for well-nourished infants. Sytscheff[3] measured 10 infants under one year of age, but computed no ratios. Howland,[4] employing Meeh's and Lissauer's measurements, has recently proposed still another method for computing the body-surface based upon a curve represented by the algebraic formula $y=mx+b$.

With these three methods in vogue for computing the body-surface, *i. e.*, that of Rubner and Heubner using the Meeh formula with the constant 11.9; that of Lissauer using the constant 10.3; and that of Howland using the algebraic curve—it can be seen that, with the great weight laid by all experimenters in infant metabolism upon the relationship between body-surface and metabolism, it is incumbent upon us to present our results on the three separate bases, although the relative values remain unaltered in all three cases. This is done in table 31,[5] the plotted values being given in figures 60, 61, and 62.

COMPARISON OF AGE AND HEAT-PRODUCTION PER SQUARE METER OF BODY-SURFACE.

According to accepted ideas we should expect to find the heat-production per square meter approximately constant for all of our infants, *i. e.*, not far from 1,000 calories per square meter of body-surface. That this value is far from constant is seen clearly in table 31, but the variations are most strikingly shown if we compare them with the age of the infant, as is done in the charts in figures 60 to 62.

In the chart in figure 60, the range in heat-production per square meter of body-surface (Meeh formula) per 24 hours is very wide, the lowest value being 656 calories for M. D., and the highest 1,239 calories for J. M. An inspection of the plot shows no average value, for even when we omit the extreme values for M. D., A. C., E. F., and J. M., the limits still remain 771 to 1,108. A larger number cluster around 875 calories, but there are too many scattering values to permit the use of 900 calories as an average value. If a line were drawn passing through the greatest number of points in this curve, it would indicate that there is a tendency for the older infants to have a higher heat-production, and yet, even with infants of the same age, wide variations are to be observed. This chart, therefore, leaves no doubt as to the lack of constancy in heat-production per unit of body-surface for the infants under observation in this research.

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[1] Miwa and Stoeltzner, Zeitschr. f. Biol. 1898, **36**, p. 314.

[2] Lissauer, Jahrb. f. Kinderheilk, 1902, **58**, p. 392.

[3] Sytscheff, Measure of volume and body-surface of children according to their ages. Dissertation, St. Petersburg, 1902. See, also Gundobin, *loc. cit.*, p. 54.

[4] See p. 22 for further explanation of this method.

[5] See p. 143.

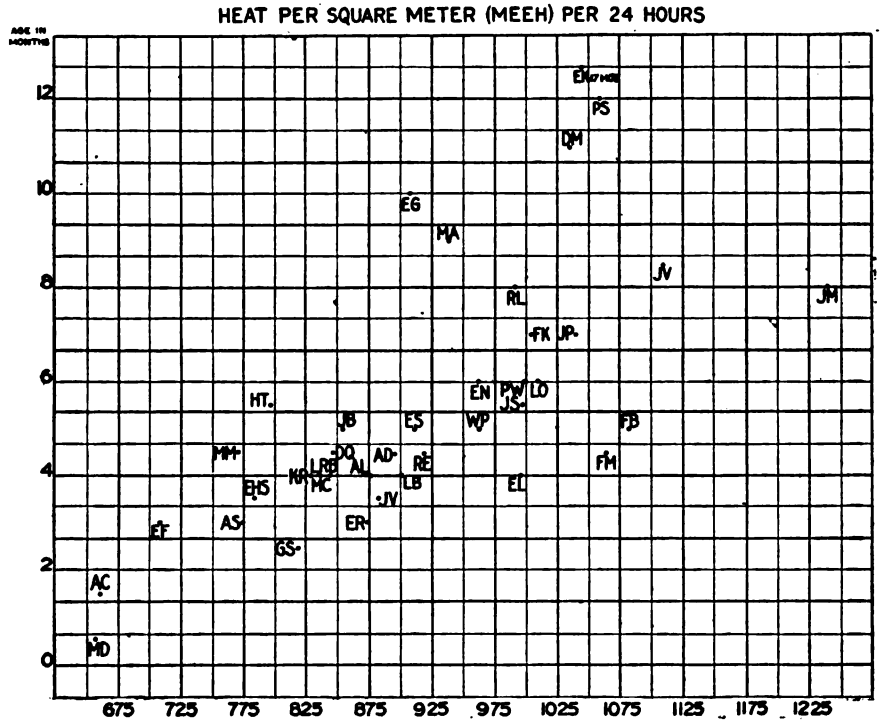

FIG. 60. Chart showing age of infants and heat-production per square meter of body-surface (Meeh formula) per 24 hours.

In the charts in figures 61 and 62, a comparison is made of the same two factors, using as a basis the Lissauer and Howland formulas respectively. The substitution by Lissauer of 10.3 for the constant 11.9 in the Meeh formula has not materially altered the picture as is shown by comparing the charts in figures 60 and 61. In the latter. the minimum value is 753 calories with M. D., and the maximum 1,432 calories with J. M., with a tendency for some of the points to collect about the value 1,025 calories. The plot in general can not be considered in any sense as indicating uniformity, although a slight general inclination is shown for older infants to have a higher heat-production on this basis.

With Howland's formula (see figure 62) the general picture presented is essentially the same. The lowest value on this basis is 739 calories with M. D., and the highest is 1,367 calories with J. M. The general tendency for the older infants to have a higher heat-production may again be inferred from an inspection of the chart in figure 62, though no definite regularity in the relationship between age and heat-production can be seen.

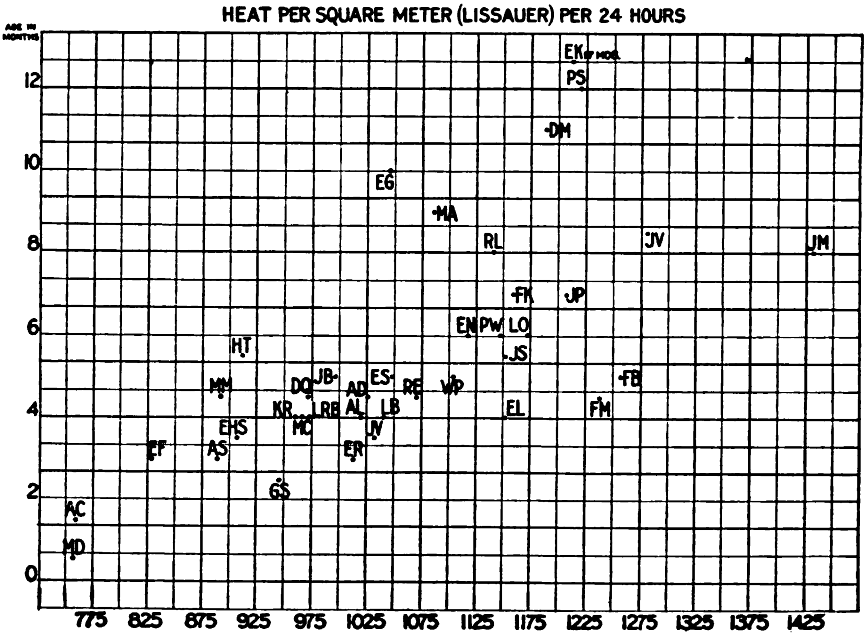

FIG. 61. Chart showing age of infants and heat-production per square meter of body-surface (Lissauer formula) per 24 hours.

It should be borne in mind that, according to the currently accepted views, the charts in figures 60, 61, and 62 should theoretically have been straight lines—that is, that the points should have grouped themselves more or less in a vertical manner. As a matter of fact, the grouping appears to be more horizontal than vertical, thus showing by a visualized method a complete absence of correlation in the heat-production per square meter of body-surface with infants of different ages.

With such large variations it was highly improbable that further comparisons on this basis would lead to any explanation of the discrepancies. Nevertheless, so at variance are these results that we have deemed it necessary to make all possible computations and comparisons and to see if definite relationships can be established for the heat-production per square meter of body-surface and the age, weight, and length of the different infants.

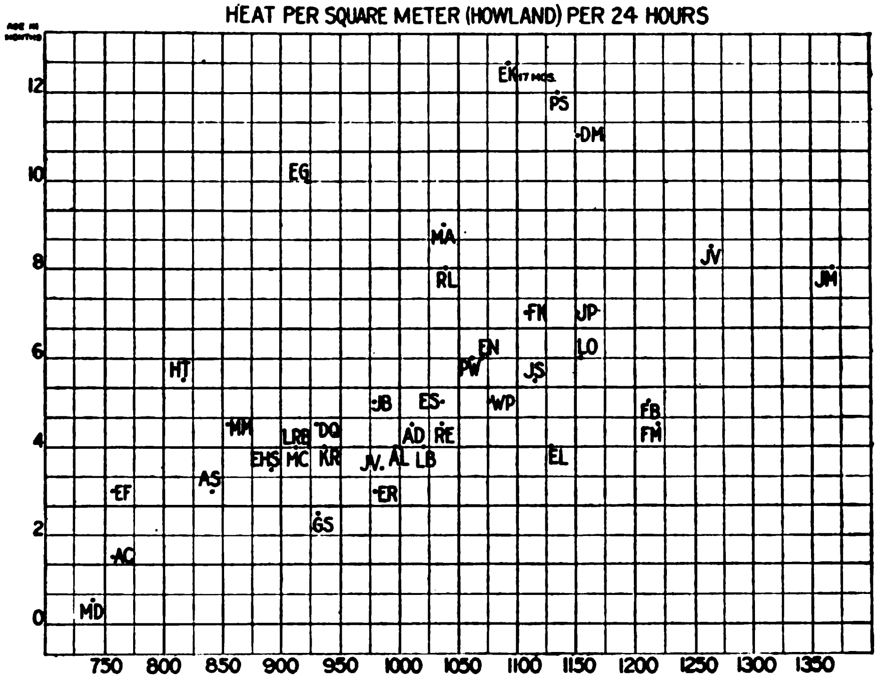

FIG. 62. Chart showing age of infants and heat-production per square meter of body-surface (Howland curve) per 24 hours.

COMPARISON OF ACTUAL BODY-WEIGHT AND HEAT-PRODUCTION PER SQUARE METER OF BODY-SURFACE.

In the charts in figures 63, 64, and 65, the heat-production per square meter of body-surface has been compared with the actual body-weight using the three formulas. In the chart on the Meeh formula given in figure 63, we should again expect according to current belief to find the values grouping themselves in a vertical line. On the contrary, the dispersion is even more marked than in the charts plotted on the basis of age, with a tendency, if any, toward a horizontal rather than a vertical alignment. The complete absence of correlation is here again strikingly shown, nor is the general picture of the relationship between actual body-weight and the heat-production per square meter of body-surface materially altered when the plots are made on the formula of Lissauer (figure 64) or on the formula of Howland (figure 65).

It is again important at this point to recall the fact that the observations made on these infants were all under constant conditions, namely, complete muscular repose and at approximately the same length of

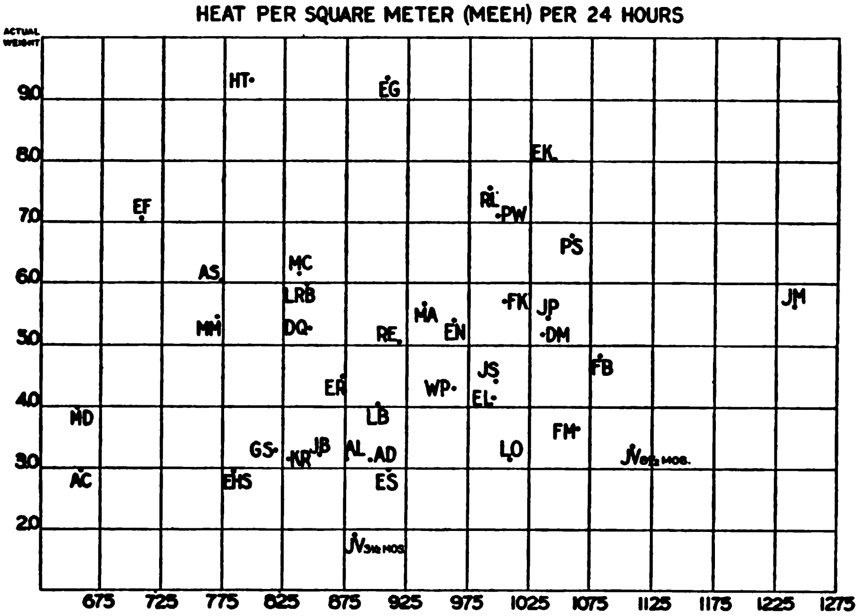

Fig. 63. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Meeh formula) per 24 hours.

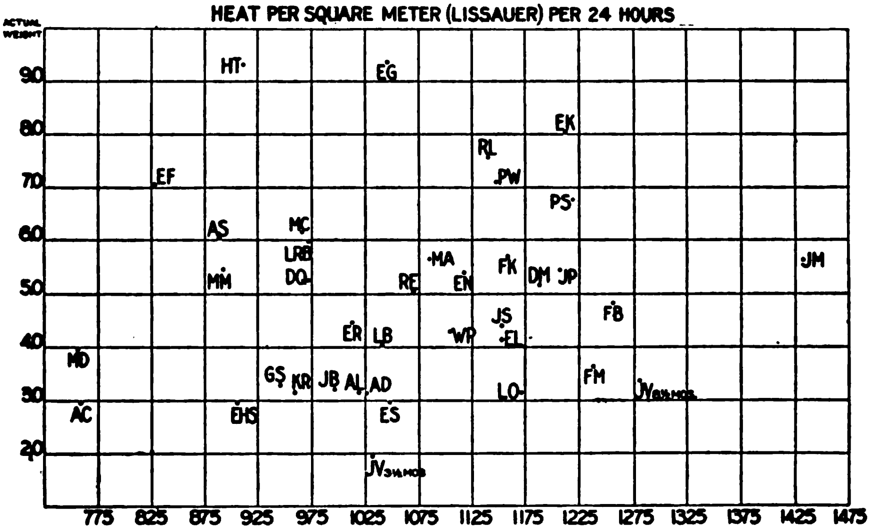

Fig. 64. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Lissauer formula) per 24 hours.

time after feeding. It is impossible, therefore, to explain these great discrepancies as being due to muscular activity, nor can they in any way be accounted for by the ingestion of food, since our experiments have shown that the food taken by these infants while under observation had no material influence upon the metabolism. Finally, it should be noted that, in general, the observations were made at substantially the same time relations to the food ingestion.

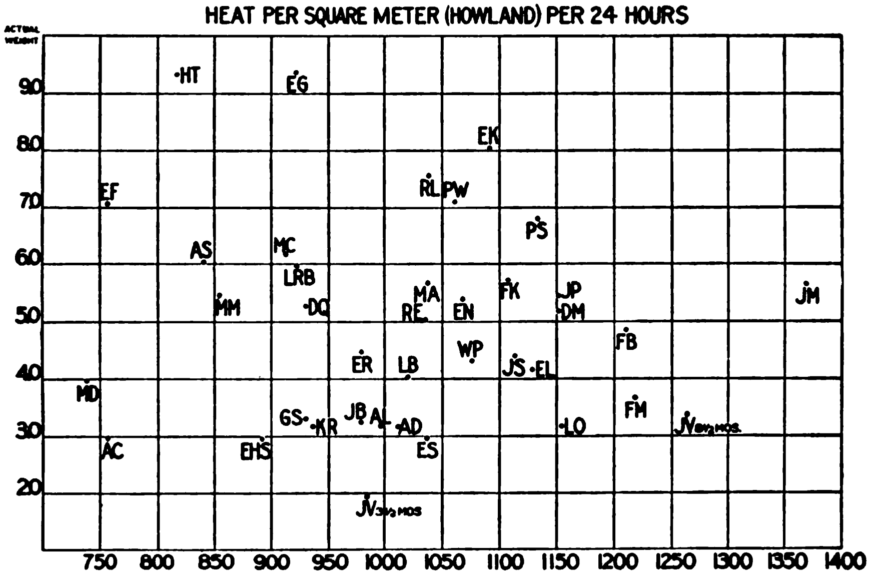

Fig. 65. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Howland curve) per 24 hours.

EFFECT ON METABOLISM OF POSSIBLE DISTURBANCE IN RELATIONSHIP BETWEEN BODY-SURFACE AND BODY-WEIGHT.

It has frequently been the custom when discrepancies in the heat-production per square meter of body-surface are found with infants, and particularly with atrophic infants, to ascribe the variation to a disturbance of the relationship between body-surface and the body-weight from which it is computed. It is essential, therefore, at this point to discuss this possibility more in detail.

The argument frequently raised is that disturbances in the relationship between body-weight and body-surface with under-weight infants precludes the use of any of the formulas now regularly used for the computing of body-surface, in that they give too small a value of body-surface for such infants. At the outset we wish to oppose this general thesis on the ground that in the most extensive and remarkably accurate series of measurements on infants with which we are familiar, namely, those of Lissauer, it is especially emphasized that 10 out of 12 of the infants were very much under weight. This will be seen by reference to table 34, which reproduces the weights of 11 of the infants measured by this investigator.[1]

As Lissauer himself points out with regret, S—i was the only case which could be called normal, although S—r was practically of normal weight. All of the other cases were noticeably under weight, far more so than our infants as a rule. Yet, in spite of this great deficiency in weight, the relationship between the body-weight and the measured body-surface was represented by the difference between the constant 10.3 used by Lissauer and 11.9, the constant of Meeh. In other words, this large variation in weight produced a maximum discrepancy of not over 15 per cent in the relationship between the body-surface as actually measured and the body-weight.

TABLE 34.—*Body-weights of infants measured for body-surface by Lissauer.*

Name.	Sex.	Age.	Body-weight.	Average weight for age obtained from Heubner.
			kilos.	*kilos.*
M—f......	M	3½ mos.	3.27	6.2
H—r......	F	3½ "	1.96	6.2
R—e......	F	3¾ "	3.37	6.3
S—e......	M	1 "	2.22	4.008
S—r......	F	1 "	3.83	4.008
M-r......	M	15 "	5.23	11.+
W-t......	M	17 days	1.73	3.6
S-t......	M	22 "	1.28	3.7
P—z......	M	3¼ mos.	2.50	6.0
H—z......	M	7½ "	3.10	8.2
S—i......	M	3⅞ "	6.18	6.3

It is furthermore of interest to note, although this is probably a mere coincidence, that one infant, especially cited by Lissauer as a normal infant (S—i), gave a constant of 10.3. When one considers that the Meeh constant of 11.9 was based upon the measurements of but two infants less than a year old, it seems probable that the Lissauer formula is more nearly accurate and that the difference in the relation between body-weight and body-surface due to under weight is not appreciable. That the opposite is true, namely, that there is no disturbance in the relationsip between body-weight and body-surface when the infant is over weight, lacks, as yet, experimental evidence for confirmation or refutation.

The possibility of the disturbance in the relationship between body-surface and body-weight in under-nourished infants has been provided for in the presentation of our data, in that the comparisons have been made upon the three bases of Meeh, Lissauer, and Howland. We frankly consider for our own work that the factor 10.3 which was most carefully determined by Lissauer is the one logically best adapted for use in computing the body-surface of the greater number of infants. We furthermore believe that Lissauer's formula would, in general, more nearly fit the requirements of observations in clinics, where the larger number of infants are under weight. On the other hand, as we have already pointed out, it is distinctly questionable whether the methods of measurement[1] have even yet been sufficiently refined or are sufficiently numerous to give a reliable method for the computation of the body-surface from the body-weight.

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[1] Lissauer, *loc. cit.*

TABLE 35.—*Heat-production per square meter of body-surface (Meeh formula) for normal infants.*

Subject.	Body-weight without clothing.	Height.	Age.		Days.	Periods.	Heat per square meter of body-surface (Meeh).
	kilos.	*cm.*	*mos.*	*days.*			*cals.*
M. D.......	3.99	..	..	17	2	4	656
M. C.......	6.17	63	4	..	3	7	837
L. R. B.....	5.99	64	4	..	4	11	844
E. G.......	9.37	74	10	..	3	5	907
R. L.......	7.58	71	8½	..	5	8	991
P. W.......	7.11	64 ?	7	..	2	5	998

Although we believe that the lack of consistency exhibited by our infants in the heat-production per square meter of body-surface may not be ascribed to the fact that these infants were distinctly under the average weight, it is of special interest to select the relatively few infants who are of normal average weight and note the relationship between the heat-production and the body-surface. This has been done in table 35, in which the heat-production per square meter has been calculated for 6 of our normal infants of average weight.

In no case were less than 4 periods used for averaging, and usually the average was drawn from a larger number of periods, the range being from 4 to 11 periods. Even with these selected infants, the variations in the heat-production per square meter of body-surface range from 656 to 998 calories. It is thus evident that the disturbance noted with our whole collection of infants in the relationship between the heat-production and the body-surface is also apparent with selected infants having a normal or approximately normal average weight.

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[1] As an interesting evidence of our initial belief in the importance and significance of the measurement of body-surface and its relationship to metabolism, we should here state that extensive preparations were made by us for the measurement of the body-surface of a number of infants, and a method was developed for securing shadow photographs of infants in various positions, the areas of the shadows being measured by a planimeter. It was our hope to establish thereby some relationship with the body-surface as measured from the shadow photograph, and by actual measurements of cadavers, and the body-weight and length. It is needless to say that with our present views in regard to the significance of body-surface in its relation to metabolism, we have not felt justified in continuing such a series of measurements.

INFLUENCE OF VARIATIONS IN THE COMPOSITION OF THE BODY UPON TOTAL HEAT-PRODUCTION.

Since a gross disturbance in the relationship existing between the body-weight and the body-surface as computed from the body-weight is highly improbable, whether the infant is atrophic or well nourished, it is important to find out, if possible, if any relationship exists between the general composition of the body and the total heat-production. Our data are sufficiently extended to permit a somewhat incomplete discussion of this important phase of the comparisons.

Heretofore, all workers in metabolism have considered only the relationship between body-weight and metabolism, or body-surface and metabolism. Since the body-surface is assumed to have a direct relationship to the body-weight, it can be seen that body-weight is the only fundamental factor which has thus far been seriously considered by investigators in comparing the metabolism of different infants.

It is obvious that when two infants are of the same weight, the shorter one will have the larger proportion of fat. Furthermore, with two infants of the same length but of different weights, the heavier infant will have the larger proportion of fat. It can be seen, therefore, that an atrophic infant, weighing 4 kilograms and 65 cm. long, when compared to a well-nourished infant of the same weight and length, would have a smaller proportion of fat. Moreover, an atrophic infant, to have the same weight and length as a normal infant, must obviously be older, and we here find a new factor entering into the comparison of infants; as yet the element of age has received scant attention. Table 31 shows that in a number of instances infants with approximately the same body-weight and the same height differ greatly in age. Unfortunately our data are not so extensive as to enable us to compare infants with absolutely the same body-weight and height, but a number of comparisons are justifiable and these have been included in table 36, which gives eight series of comparisons of the total heat produced, the heat-production per kilogram of body-weight, and the heat-production per square meter of body-surface for infants with the same body-weight and height but of different ages. The difficulties incidental to measuring exactly the length of infants make these measurements slightly problematical and there may be a variation of plus or minus 1 cm. We have, therefore, compared infants whose lengths do not vary more than 1 cm. The variations in weight are all within a few tenths of a kilogram.

We note instantly several striking points in the data as presented. In each comparison the values for the younger infant are given first, and it will be seen that the older infant has invariably the larger total heat-production. The greatest difference is 182 calories in the comparison of M. M. with J. M., the lowest difference being that of 16 calories between E. N. and D. M. Aside from this latter comparison, the increase in the heat-production for the older infants is very considerable. The heat-production per kilogram of body-weight and per square meter of body-surface also show this increase in the same general proportion, since the body-weights of the infants compared are essentially the same in all cases.

TABLE 36.—*Comparison of heat-production of infants of like body-weight and height, but of different ages.*

Subject.	Sex.	Body-weight.	Height.	Age.	Heat produced. Per 24 hours.	Heat produced. Per kilogram per 24 hours.	Heat produced. Per square meter (Meeh) per 24 hours.
		kilos.	*cm.*	*mos.*	*cals.*	*cals.*	*cals.*
A. L.	F	3.18	53	4	226	71	876
J. V.	F	3.38	53	8½	297	88	1108
E. N.	F	5.40	66	6	353	66	962
D. M.	M	5.18	66	11	369	71	1034
M. M.	F	5.47	62	4½	285	52	770
J. M.	M	5.63	62	8	467	83	1239
D. Q.	M	5.28	62	4½	305	57	846
J. P.	M	5.45	63	7	387	70	1039
M. M.	F	5.47	62	4½	285	52	770
J. P.	M	5.45	63	7	387	70	1039
D. Q.	M	5.28	62	4½	305	57	846
J. M.	M	5.63	62	8	467	83	1239
L. R. B.	F	5.99	64	4	331	55	844
F. K.	M	5.71	65	7	381	67	1003
H. T.	M	9.33	75 ?	5½	420	45	797
E. G.	M	9.37	74	10	479	51	907

In the two series of comparisons in which the youngest infant is approximately 6 months old, namely, those comparing E. N. with D. M. and H. T. with E. G., the increase in the heat-production for the older infant is not so great. In the latter comparison, E. G. was of normal weight while H. T. was over weight, so that the excessive amount of fat actually lowered the total heat-production of the younger infant H. T. It is therefore clear that with the older infants, which were in most instances distinctly under weight, there was a deficiency in the fat with an accompanying increase in the proportion of active protoplasmic tissue. While this method of comparing the metabolism of infants on the basis of weight, height, and age gives a clue to the probable preponderance of fat or active protoplasmic tissue, it is obvious that no quantitative relationship can be established on this basis.

The striking comparison between M. M. and J. M. is particularly worthy of consideration, inasmuch as the value for M. M. is derived from observations on three days, and a total of seven satisfactory periods were available for averaging, while with J. M. the data were secured on two days with six periods for comparison. Here, with a difference of 3½ months in the age, there was obviously a much greater proportion of active protoplasmic tissue with the older infant, J. M.

That the active protoplasmic tissue determined to a very considerable extent the total katabolism, not only with J. M., but with all of the older under-nourished infants, is highly probable and we find ourselves thoroughly convinced that the metabolism is determined not by the body-surface but by the active mass of protoplasmic tissue. With normal infants of varying weights, it is quite probable that the active mass of protoplasmic tissue varies directly with the age. Since it has been shown that not only body-surface but more recently that the blood-volume, the size of the aorta, and the size of the trachea with several species of mammals bear a direct relationship to the cube root of the square of the body-weight,[1] it is not surprising that most experimenters have observed that with adults the metabolism is roughly proportional to the body-surface. If the blood-volume and the area of the trachea and the aorta are proportional to the cube root of the square of the body-weight, it is reasonable to suppose that the active mass of protoplasmic tissue may develop normally on this ratio. When there are marked variations from the average, as with excessive or with deficient adipose tissue, this relationship can not be expected to hold.

If, therefore, it is maintained that the total metabolism is proportional to the body-surface, it should be stated that this is not due to the fact that there is a loss of heat from the body-surface and that Newton's law of cooling determines the intensity of the metabolism, but that with normal individuals the body-surface, blood-volume, the area of the trachea and the aorta, and probably the active mass of protoplasmic tissue, are all in simple mathematical relation to the body-weight. Thus the apparent relationship which has previously been observed between the heat-output and the body-surface with normal or nearly normal individuals has an explanation in that with such individuals a simple relation exists between the body-surface, blood-volume, body-weight, and the mass of active protoplasmic tissue.

In our series of observations we have attempted to eliminate completely all muscular activity, to make the experiments under approximately the same conditions as to nutriment, to select such a diet as was least stimulating to the katabolism, and to have our subject for the most part in deep sleep, thus eliminating psychic disturbances. With these conditions we hoped to obtain the fundamental minimum metabolism, upon which we might base our discussion.

The basal metabolism as we have outlined above, can not in any wise be considered a direct function of the body-weight and the body-surface, and particularly has no relationship with body-surface on the basis of the law of cooling bodies.

We believe that our evidence points strongly and conclusively to the fact that the active mass of protoplasmic tissue determines the fundamental metabolism. The absence as yet of a direct mathematical measure of the proportion of active protoplasmic tissue does not, we believe, in any wise affect the convincing nature of our evidence.

---

[1] Dreyer and Ray, Phil. Trans., 1909–1910, **201**, ser. B, p. 133; Dreyer, Ray, and Walker, Proc. Roy. Soc., 1912–1913, **86**, ser. B, pp. 39 and 56.

METABOLISM AND GROWTH FROM BIRTH TO PUBERTY

BY

FRANCIS G. BENEDICT

AND

FRITZ B. TALBOT

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METABOLISM AND GROWTH FROM BIRTH TO PUBERTY.

INTRODUCTION.

In the past decade the trend of thought in the physiology of growth has been towards a chemical analysis of the several growth factors. The embryonic animal (which with mammals receives nourishment from its mother through the placenta, and with other animals from the previously deposited food material in the egg) grows in accordance with the nutrients supplied. After birth various types of foods are brought to it by the mother or by other agencies. The selection of the diet best fitted, both in amount and in quality, to acquire growth has received a great deal of experimental attention. The importance of the mineral constituents and the nature of the proteins used in the construction of new tissue have been emphasized; particularly, the so-called "unidentified food accessory substances," which make for growth, have been exhaustively studied by Hopkins,[1] Osborne and Mendel,[2] and McCollum.[3] As a result of these extensive investigations of the subject, it is clear that a large number of factors, heretofore almost neglected in research, are absolutely essential for the proper growth of the immature animal.

With a study of these essentials there has proceeded, although perhaps with less intensity, a study of certain physiological constants characteristic of the immature animal, particularly of the human animal. While the anthropologists have given us extensive measurements of the growth in that period of development in which growth is most marked, *i. e.*, in the earlier years of life, relatively little is known regarding the fundamental basal metabolism during this period. The Nutrition Laboratory, in the belief that a careful survey should be made of the metabolism of all mankind from birth to old age, has been occupied for nearly a decade in the charting of this little-known field of human basal metabolism. The writers' special province has been that of infants and children. As an indication of the extent and thoroughness of the original program in its several subdivisions, we may call attention to our report of a research on the physiology of the new-born infant, in which over 100 new-born infants were studied, many a few minutes after their birth, and all during the first week of life.[1] An earlier report of a study of infants has also been published, with the primary object of indicating methods of study and certain physiological correlations, particularly pulse-rate and metabolism.[2] At the time of this earlier report, the number of normal individuals obtainable was relatively few and a somewhat large number of atrophic infants, with a few pathological cases, were included to show what might be expected for variation in metabolism in the hospital ward. With the completion of the study of new-born infants, the next step was the study of the basal metabolism of children at various ages from one week to puberty. The results of this latest investigation we purpose presenting in this report.

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[1] Hopkins, Journ. Physiol., 1912, 44, p. 425.
[2] Osborne and Mendel, Carnegie Inst. Wash. Pub. No. 156, 1911.
[3] McCollum, The newer knowledge of nutrition. New York, 1918.

BASAL METABOLISM.

Basal metabolism may be considered as the sum total of all the vital activities of the quiet organism in the post-absorptive condition, *i. e.*, the minimum or maintenance metabolism unaffected by extraneous factors. This may be expressed in terms of heat produced or of gaseous exchange incidental to heat production (carbon-dioxide production and oxygen consumption). Using this basal metabolism as a standard, we may then measure definitely the effect of superimposed factors.

In these studies of the basal metabolism from birth to puberty, it has been our aim to determine the metabolism at the different ages under identical conditions as far as possible, so that the results may be entirely comparable. To obtain comparable results with individuals of varying ages, certain experimental conditions should exist. In the first place, in view of the pronounced influence of muscular activity upon basal metabolism, it is desirable that all subjects should have the same degree of muscular repose. An ideal condition would be complete muscular repose. The difficulty of securing such repose with young children is obvious, for infants of one or two years of age differ widely in muscular movements and temperament from an adolescent boy or girl. With adults and older children the muscular activity may be voluntarily so controlled that the increase in metabolism due to activity, even in restless periods, will be but 15 to 20 per cent. With crying children, with whom the activity is involuntary, the increment was found in our earlier studies to be at times over 200 per cent and on an average 65 per cent.[3]

Second, it may be stated that, theoretically at least, the ingestion of any energy-producing food-material increases the metabolism by stimulating the cells to greater activity. This stimulus is greatest with protein foods and least with fats. To secure comparable results, therefore, the ideal condition would be to study all subjects in the post-absorptive state, *i. e.*, about 12 hours after the last meal, when the influence of the preceding diet had disappeared. With such differences in dietetic habits, times of eating, and stomach capacity as exist between infants a year old and children 12 years old, the obtaining of ideally comparable conditions in this respect is likewise difficult.

---

[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914. For a briefer report, see Benedict and Talbot, Am. Journ. Diseases of Children, 1914, 8, p. 1.

[3] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, p. 112, table 17.

The third factor to be considered in determining the basal metabolism is that of sleep. While certain observations made in a number of laboratories imply that sleep, *per se*, is without profound effect upon the metabolism, yet in the light of our experience in this laboratory during the past decade we are strongly inclined to think that this is an erroneous conception. Furthermore, the opportunities for error in the usual methods of determination of the metabolism during deep sleep are great. When breathing appliances, such as mouthpiece, nosepieces, or mask, are used in our experiments, the subjects have been for the most part required to keep awake on the general ground that with sleep the facial muscles relax, especially those about the mouth, and there is danger of leakage of air under these conditions. Practically the only method of experimenting which gives dependable results with a sleeping subject is the chamber method, *i. e.*, with the subject asleep inside one of the several forms of respiration chamber. That sleep is a factor of great significance was clearly demonstrated in this laboratory with the subject of a fasting experiment.[1] Recent experiments, as yet unpublished, show that the metabolism of a sleeping subject differs appreciably from that of a subject awake, even though in both periods there is the greatest degree of muscular repose.

A cursory examination of the data presented in the literature on the metabolism of children shows a wide diversity of results. The literature on the metabolism of infants, especially of the new-born, has already been reviewed briefly in the two publications giving the results of our earlier studies.[2] While it is unnecessary to refer here in detail to the work already cited, it seems desirable, before giving the results of our own observations, to supplement the previous review of the literature by a citation of the observations made by other workers with older children.

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[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, pp. 343 *et seq.*

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, pp. 11 to 22, and Carnegie Inst. Wash. Pub. No. 233, 1915, pp. 12 to 38.

PREVIOUS STUDIES OF METABOLISM OF CHILDREN.

In considering the previous studies with children, one must differentiate sharply between measurements of metabolism which are possible only with respiration apparatus or calorimeters and the computation of the energy requirement for the day from a statistical study of the diets consumed by the infants or children observed. The researches on energy transformation of children may be divided into two classes: (1) those by the indirect method, in which a study is made of the respiratory exchange by means of some form of respiration chamber, and (2) those by direct calorimetry, in which the heat output is determined with a calorimeter.

Beginning with the calorimetric researches of Richet, a number of French writers conducted researches on the metabolism of infants by direct calorimetry, several of these observations being made with calorimeters devised by d'Arsonval. These studies have already been summarized in one of our earlier reports,[1] but they have little present-day value, for the investigators disregarded the somewhat considerable withdrawal of heat from the body by the vaporization of water and gave no quantitative information regarding muscular activity. Furthermore, much of the French work was done with abnormal children, while our report deals exclusively with the physiology of normal youth.

Calorimetric observations of the basal metabolism of children have also been made by Du Bois and associates, which will be cited in some detail later. The greater part of their computations and the deductions therefrom are, however, based upon indirect calorimetry rather than upon direct calorimetric measurements. The observations of the basal metabolism of infants made by Howland with Lusk's calorimeter,[2] an abstract of which was given in our earlier report, are, so far as we know, the only successful studies of infants which have thus far been made by the direct method. Practically all of the observations cited in the following pages, therefore, are those made by the indirect method.

Andral and Gavarret, 1843.—The first experiments on children, made by Andral and Gavarret,[3] although having mainly an historical interest, should certainly be considered in any careful analysis of the literature. Since at this early date the authors laid special stress upon the influence of puberty, the figures are, in the light of modern studies at this age, worthy of even greater consideration. Andral and Gavarret employed a copper mask attached to the subject's face and collected the expired air in large glass globes, this air being subsequently analyzed. They report a large series of experiments (8 to 13 minutes long) with a great many individuals, some of them children. The experiments were all made in the early afternoon and at the same interval after food, and an attempt was made on the part of the experimenters to have all subjects with the same degree of muscular activity, presumably in the sitting position. Although reported on the basis of carbon per hour, their data have been recalculated to the basis of carbon dioxide by Sondén and Tigerstedt[1] and are presented in table 1 as given by them, together with our computations of the heat production per 24 hours.

---

[1] Detailed references to the researches of these investigators are given in Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, pp. 11 to 14.

[2] Howland, Proc. Soc. Exp. Biol. and Med., 1911, 8, p. 63; Hoppe-Seyler's Zeitschr. f. Physiol. Chem., 1911, 74, p. 1; Trans. 15th Int. Congress on Hygiene and Demography, Washington, 1913, 2, p. 438. Cited by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 22.

[3] Andral and Gavarret, Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 129.

TABLE 1.—*Metabolism of boys and girls (Andral and Gavarret).*

Subjects.	Age.	Carbon per hour.	Carbon dioxide produced per hour.[1]	Heat (computed) per 24 hours.[3]	Remarks regarding muscular system.	
	yrs.	*grams*	*grams*	*cals.*		
Boys...	8	5.0	[2]18.3	1,318	Average.	
	10	6.8	24.9	1,793	Well developed.	
	11	7.6	27.9	2,009	Do.	
	12	7.4	27.1	1,951	Average.	
	12	8.3	30.4	2,189	Very well developed.	
	14	8.2	30.1	2,167	Average.	
	15	8.7	31.9	2,297	Do.	
Girls...	10	6.0	22.0	1,584	Well developed.	Puberty not established.
	11	6.2	22.8	1,642	Do.	
	13	6.3	23.1	1,663	Mediocre.	
	15½	7.1	26.1	1,879	Very well developed.	
	15½	6.3	23.1	1,663	Average; puberty established.	

[1] Computed by Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, pp. 54 and 56.
[2] Sondén and Tigerstedt give 16.7 gms. CO_2; this value corrected by us.
[3] Heat computed from carbon-dioxide production, assuming 3 calories per gram of carbon dioxide.

The authors conclude that with males there is a steady increase in the carbon-dioxide production between 8 and 30 years. At the time of puberty this increase suddenly becomes very large. Thus, the amount of carbon burned in one hour's time increases progressively from 5 grams in the case of a boy 8 years old to 8.7 grams in the case of a boy 15 years old, while with a young man of 16 years the amount was 10.2 grams. With well-developed males from 20 to 28 years of age the values for carbon increase gradually to 11.2 grams and 12.4 grams.

With the females there is likewise an increase in carbon-dioxide production with increasing age, but at the time of puberty this increase suddenly ceases and the amount of carbon-dioxide produced remains stationary, being nearly what it was in childhood. Thus, with a girl 13 years old the carbon burned per hour was 6.3 grams; with a girl 15½ years old, who had not yet reached puberty, the value found was 7.1 grams, while with another girl of the same age, who had reached puberty, the value was only 6.3 grams.

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[1] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, pp. 54 and 56.

Comparing the two sexes, Andral and Gavarret conclude that the male child burns more carbon than the female, on the average about 1 gram more of carbon per hour.

The absence of weights and heights in the report lessens its value, but in view of the subsequent researches of Du Bois and certain data accumulated by us these early conclusions with regard to the influence of puberty are of special significance.

Scharling, 1843.—Publishing simultaneously with Andral and Gavarret, Scharling[1] reports experiments with a number of subjects, two of them children of the age-range we are considering in this report, one a boy of 9¾ years of age weighing 22 kg., and one a girl of 10 years weighing 23 kg. Scharling's apparatus was a respiration chamber, a brief description of which has been given in a previous report.[2] The values of special significance in connection with the discussion of basal metabolism are those on the boy and girl in table 2.

TABLE 2.—*Basal metabolism of children (Scharling).*

Subject.	Age.	Body-weight.	Carbon per hour in Danish "gran."	Carbon dioxide per hour.[1]	Carbon dioxide per kg. per 24 hours.	Heat (computed) per 24 hours.[2]	Heat (computed) per kg. per 24 hours.
	yrs.	*kilos.*		*grams.*	*grams.*	*cals.*	*cals.*
Boy.....	9¾	22	76.2	17.2	18.7	1,238	56.3
			74.8	16.9	18.4	1,217	55.3
Girl.....	10	23	65.5	15.0	15.7	1,080	47.0
			75.1	17.2	17.9	1,238	53.8

[1] In recalculating carbon to basis of carbon dioxide, estimated that 1 Danish "gran" (the measure used by Scharling) equals 0.0621 gram.

[2] Heat computed from carbon-dioxide production, assuming 3 calories per gram of carbon dioxide.

Forster, 1877.—The next recorded observations on children are the studies made by Forster[3] in Munich in 1877. These are presented in a fragmentary manner in somewhat inaccessible publications. Certain of Forster's results were abstracted in our two previous publications, but as his studies have a special historical interest as being the first made by the Pettenkofer and Voit method, and include observations on older children, it seems advisable to consider them somewhat more extensively here. In his recognition of the importance of a study of the metabolism of youth, Forster was undoubtedly stimulated by the wonderful observations of Pettenkofer and Voit. The statement made in our earlier publication,[1] that he used the *large* Pettenkofer-Voit respiration chamber, is obviously erroneous; we have been unable to find a description of the exact size of chamber that he used. In amplification of the records of Forster's investigations previously reported by us, the following data should be given:

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[1] Scharling, Ann. d. Chem. u. Pharm., 1843, 45, p. 214; reprinted in detail in Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 478.

[2] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 13.

[3] Forster, Amtl. Ber. d. 50 Versamml. deutsch. Naturf. u. Aerzte in München, 1877, p. 355; also v. Ziemssen's Handbuch der Hygiene, Leipsic, 1882, 1, p. 76. See also Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., 1899, Suppbd., p. 356.

Forster[2] states that he studied a number of children varying in age from 14 days to 13 years, using a Pettenkofer-Voit respiration chamber and determining the carbon-dioxide excretion. The experiments with nursing infants, which continued from 3 to 5 hours each, were made in the intervals between the nursings. With the other children the experiments were made in the morning. The supper given the children the night before the experiment consisted of milk with a little bread; from 1½ to 2 hours before the beginning of the experiment, they all received 100 grams of milk and a small piece of bread (about 50 grams). During the experiments the nursing infants slept the greater part of the time; the other children remained very quiet, for the most of the time sitting and with nothing special to do. In conformity with the usage of a number of writers at about that period, Forster reported his results as grams of carbon-dioxide excreted per hour for each 10 kg. of body-weight. The results are given in table 3.

TABLE 3.—*Carbon-dioxide production of children* (*Forster*)

Subject.	Age.	Carbon-dioxide production per 10 kg. per hour.
		grams.
Girl (nursing infant)	14 days	9.0
Boys and girls	3 to 5 years	11.7
Do.	6 to 7 years	11.7
Do.	9 to 13 years	8.9

These values, which are not far from 10 to 12 grams per hour for each 10 kg. of body-weight, Forster compares with those obtained by Pettenkofer and Voit for men calculated to the same basis of body-weight. The values for adults are, for the most part, one-half of those found with the children. Forster concluded that, since the children during the experiment were usually quiet and with approximate hunger, there is a very much greater oxidation of nitrogen-free material with children than with adults under the same external conditions. He pointed out that this is likewise true even during sleep, when the metabolism is lower, for Lewin's adult subject[1] gave off in sleep 3.5 grams of carbon dioxide per 10 kg. of body-weight per hour, while Forster's sleeping infant gave off 9 grams of carbon dioxide.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 11.

[2] Forster, v. Ziemssen's Handbuch der Hygiene, Leipsic, 1882, 1, p. 76.

Speck, 1889.—Speck's observations on children really antedated the work of Forster, for, although his results were not published until 1889,[2] experiments on a 13-year-old girl, weighing 35 kg., were begun on September 2, 1871, and continued at intervals for two or three weeks. Speck points out that this child used less oxygen than a normal man, but when the results were computed on the basis of oxygen consumption per kilogram of body-weight the metabolism of the child appeared to be more intensive than that of the adult. All the experiments with this subject were made in the standing position and without food. Beginning September 5, 1877, six experiments in about two weeks were made with a 13-year-old boy, weighing 38 kg. During these observations the boy was without food and sat reading quietly. Both the total carbon-dioxide production and the oxygen consumption were less than with the average man, but much higher when computed on the basis of body-weight. Thus the total oxygen consumption was 239 c. c. per minute and 6.3 c. c. per kilogram of body-weight; the respiratory quotient was 0.824. Still another series of experiments was made by Speck August 22 to 29, 1881, the subject being a 10-year-old girl, weighing 25.4 kg. This girl, when studied 5 hours after breakfast and while she was sitting quietly reading, gave low values as compared to those obtained with a man, but on the basis of body-weight the results were much higher. The average total oxygen consumption was 172 c. c. per minute and 6.9 c. c. per kilogram of body-weight per minute; the respiratory quotient was 0.855. Since a normal man gave about 4 c. c. of oxygen per kilogram of body-weight per minute, he concluded that a small body absorbs relatively more oxygen than a larger one and that during the years of growth the oxygen absorption is greater than with adults; furthermore, that under like conditions males have a greater metabolism than females.

As Speck's experiments were made with the subject sitting (and in one instance standing) instead of with the subject lying, and in a number of instances with food in the stomach, the results are not strictly comparable with those of modern work. It is, however, significant that Speck's conclusions, based upon these physiological observations with persons of various ages, and particularly with himself, have been unaltered by the results obtained by most modern writers. His conclusions regarding metabolism during youth are in accord with most subsequent work.

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[1] Lewin, Zeitschr. f. Biol., 1881, 17, p. 71.

[2] Speck, Physiologie des menschlichen Athmens, Leipsic, 1892, p. iv

Sondén and Tigerstedt, 1895.—Concurrently with the description of the large respiration chamber constructed in Stockholm, Sondén and Tigerstedt reported an extensive series of observations of the resting metabolism of groups of individuals of various ages inside the respiration chamber.[1] The prime object of their study was to find the carbon-dioxide output of groups of individuals for use in determining the needs of school-houses and other public buildings for ventilation. Accordingly the investigators attempted to adjust the conditions of their experiments to comply so far as possible with the demands of the rooms and buildings under consideration. The subjects were always in the sitting position, usually after a breakfast, and not infrequently were eating small amounts of candy or apples. The experimental conditions were therefore not ideal for measurements of the basal metabolism. It is no adverse criticism of this wholly remarkable research to state frankly that the results are of no particular value for comparison with later experiments carried out with the primary object of measuring basal metabolism. Notwithstanding this, probably no one research has contributed more to general information as to the caloric requirements of human individuals at different ages than has this study of Sondén and Tigerstedt. The apparatus permitted the determination of the carbon-dioxide consumption only, but the investigators were able to compute the energy requirement from this with a considerable degree of accuracy, especially when the food conditions existing prior to and during the experiments are considered.

The experiments were made with subjects varying widely in age, but our own interest in the series at this time centers on the ages prior to puberty. Fortunately their research included an extensive series on children of both sexes, the studies usually being made on groups of six subjects. The boys ranged in age from 7 years and 314 days to 14 years and 199 days, and the girls from 7 years and 316 days to 14 years and 15 days. All of the children were taken from the schools in Stockholm and remained reasonably quiet during the observations, sitting in chairs and reading. In most of the experiments they ate apples and occasionally candy, but every effort was made by the experimenters to minimize the extraneous muscular activity. The results obtained with both boys and girls are given in table 4, but in considering the data it should be borne in mind that they are not primarily basal values. Sondén and Tigerstedt report their results as carbon dioxide excreted per 6 individuals and per half hour in grams. In presenting the data here we have converted them to calories per kilogram per 24 hours per individual, using the respiratory quotient 0.90 and the calorific value of carbon dioxide for this respiratory quotient, *i. e.*, 2.785 calories per gram of carbon dioxide.

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[1] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, p. 1.

TABLE 4.—*Minimum carbon-dioxide production and heat production of boys and girls (Sondén and Tigerstedt).*

Subjects.	Average age.		Average body-weight (without clothing).	Carbon-dioxide production per individual per hour.	Heat (computed) per kg. per 24 hrs.[1]
	yrs.	*days.*	*kilos.*	*grams.*	*cals.*
Boys....	7	314	20.1	20.7	68.8
	9	217	27.5	28.0	68.1
	10	192	30.2	30.7	67.9
	11	143	31.6	30.3	64.1
	12	173	34.1	30.7	60.2
	13	313	44.5	43.0	64.6
	14	199	45.3	39.3	58.0
Girls....	7	316	21.8	22.3	68.4
	9	334	26.6	19.7	49.5
	11	57	31.0	24.0	51.7
	12	68	36.2	25.7	47.5
	13	53	39.5	25.0	42.3
	14	15	44.3	27.0	40.7

[1] In computing heat assumed respiratory quotient of 0.90.

Usually the observations continued for periods of 4½ hours. In order to approximate the minimum value for comparison purposes, we have tabulated only the *absolute minimum* found in the results. This was done on the theory that this minimum value represents the actual minimum metabolism during the period, for otherwise there would be an error in the experimental technique, which is improbable in view of the usual accuracy in experimentation of the Scandinavian investigators.[1]

Recognizing the importance of obtaining data as nearly as possible during complete muscular repose, Sondén and Tigerstedt likewise made a few experiments with individuals who slept inside the respiration chamber, these including two experiments with boys. The first was made with a boy 11 years and 2 months old, weighing without clothing 32 kg. The experiment began at 6 p.m. The subject ate supper inside the chamber at 8^h 15^m p.m., took milk at 10^h 30^m p.m., and then went immediately to bed. The carbon-dioxide excretion was determined in 2-hour periods throughout the night. The minimum values were found between 2 and 6 a.m., the values for the two periods being 41 and 37 grams, respectively. The latter figure was the absolute minimum value for the carbon-dioxide production per 2 hours. The second experiment was made with a boy 12 years of age, weighing without clothing 38.3 kg. The experimental conditions were almost identical with those of the first experiment; his last meal prior to the experiment was at 4 p.m. He went to bed at 10 p.m. The minimum carbon-dioxide production was found at 2 a.m., *i. e.*, 40 grams per 2 hours. The carbon-dioxide excretion in the period just preceding the minimum period was 41 grams and that in the period following was 42 grams. For computing the caloric output during this time, we are justified in using the respiratory quotient of 0.90 for the first experiment and probably 0.87 for the second experiment. On this basis the minimum caloric requirements for these two boys would be as given in table 5. These values may more properly be used for purposes of comparison with our own results, as they were obtained with the subject in the lying position, probably in deep sleep, which in considerable part may offset the influence of food. No night experiments during sleep were made with girls.

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[1] For the one apparent pronounced exception to the usual extraordinary accuracy of the Sondén and Tigerstedt technique, see critique of von Willebrand's work, page 14 of this monograph.

TABLE 5.—*Minimum metabolism of boys during sleep (Sondén and Tigerstedt).*

	Age, 11 years 2 months.	Age. 12 years.	Remarks.
Body-weight, without clothing, kilos.	32.05	38.30	In computing heat, assumed a respiratory quotient of 0.90 for the 11-year old boy and of 0.87 for the 12-year old boy, as the latter had had somewhat less food before retiring for the night.
Carbon-dioxide production per hour................grams.	18.5	20.0	
Heat, computed, per 24 hours, cals.	1,237	1,373	

Hellström, 1900.—Employing presumably the large Stockholm respiration chamber, Hellström[1] studied the metabolism of a 9-year-old child weighing 23.2 kg. and found that the child had a heat production of 63 calories per kilogram per 24 hours or 1,499 calories per square meter per 24 hours. Since the original place of publication of Hellström's article has been inaccessible to us, we have had to rely upon scattered statements concerning this experiment by von Willebrand,[2] by R. Tigerstedt,[3] and more recently by C. Tigerstedt.[4] As we have no information at hand with regard to the activity of the child or the height and sex, the experiment is cited here simply as a matter of historical record.

Rubner, 1902.—Rubner published an interesting series of observations on two brothers, one fat and the other thin; also a few experiments on two other boys.[5] As at that time the importance of muscular rest in measurements of basal metabolism had not been so greatly emphasized as at present, these children were allowed entire freedom of movement inside the respiration chamber. The two brothers remained in the chamber for 22 out of the 24 hours, the other two boys only 4 hours. As a result of the experimental technique Rubner doubtless had data for some periods in which the subjects were asleep, but these were not published—a fact to be regretted, for although the data were contaminated by the fact that food had been taken previously, it is highly probable that the compensatory influence of sleep would in large part offset the stimulus due to the food. Since these results are not available, we are unable to use for comparison any of the data obtained by Rubner in this important research.

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[1] Hellström, Studier öfver mjölken såsom föda, Helsingfors, 1900, p. 132.

[2] von Willebrand, Finska Läkaresällskapets Handlingar, 1907, 49, p. 421.

[3] R. Tigerstedt, Nagel's Handbuch d. Physiol., Braunschweig, 1909, 1, p. 476.

[4] C. Tigerstedt, Ueber die Nahrungszufuhr des Menschen in ihrer Abhängigkeit von Alter, Geschlecht und Beruf, Helsingfors, 1915, p. 77; see also Skand. Arch. f. Physiol., 1916, 34, p. 151.

[5] Rubner, Beiträge zur Ernährung im Knabenalter, Berlin, 1902.

Rubner compares the values found with these children with those reported by Sondén and Tigerstedt. In almost every instance he finds that the carbon-dioxide production per square meter per hour noted by Sondén and Tigerstedt was greater than that found by himself. Rubner does not believe these differences can be entirely accounted for by the restlessness of the subjects, although this must play a considerable rôle. We find ourselves in full accord with Rubner's severe criticism of the Sondén and Tigerstedt data, especially as to their use for comparison; we likewise believe that values obtained on this basis can not be used for a satisfactory demonstration of a material alteration in the basal metabolism of youth as compared with that in old age. It still remains a fact, however, that practically all of the criticisms raised by Rubner against the experiments of Sondén and Tigerstedt also apply to Rubner's own experiments. For instance, Rubner criticizes the fact that Sondén and Tigerstedt's subjects received food, but the process of digestion likewise had a part in his own experiments, although not so great as in those of Sondén and Tigerstedt. He furthermore takes exception to the fact that Sondén and Tigerstedt's subjects moved about in the chamber or were restless, but his subjects moved and indeed walked about in the chamber at times. Rubner's criticisms make it especially clear that only data obtained in the post-absorptive condition and in complete muscular repose are ideally suitable for comparing the metabolism of individuals of different ages. These conditions were not secured by either Sondén and Tigerstedt or by Rubner, although the values obtained by the Scandinavian investigators with the two boys studied throughout the night approximate very closely the basal metabolism, *i. e.*, very nearly comply with basal conditions and prerequisites.

Since Rubner wrote so late as 1902, it is somewhat surprising that no mention was made of the research of Magnus-Levy and Falk published in 1899, which met all of the objections raised by Rubner to the Sondén and Tigerstedt experiments. These experiments of Magnus-Levy and Falk were made, however, for the most part during relatively short periods, and Rubner strongly objects to respiration experiments made in short periods, an objection with which we can not agree. Rubner's chief conclusion is that the metabolism of nursing infants per square meter of body-surface is no larger than that of adults, although he does find an increased value for young boys.

This increase he attributes wholly to differences in restlessness and activity and the greater intensity of development of the muscular system, an inherent restlessness which he thinks can not be controlled with young boys. If his results obtained during sleep had been reported, much more definite conclusions could have been drawn.

Magnus-Levy and Falk, 1899.—Magnus-Levy and Falk[1] presented in 1899 the results of the first systematic study of the basal metabolism of normal individuals from childhood to old age. This research was carried out with all the precautions exacted by the Zuntz school as to quietness and accuracy of technique. The mouthpiece and the Zuntz-Geppert apparatus in general were used for the study of the basal metabolism of 11 boys and 9 girls, all 14 years old or younger.

TABLE 6.—*Basal heat production of boys and girls (in lying position) (Magnus-Levy and Falk)*

Age, years.	Body-weight (without clothing).	Height.	Body-surface (height-weight chart).	Heat (computed)			Heat per 24 hrs. predicted by multiple prediction (adult) formula.[1]	Computed less predicted.[1]	Percentage difference.[1]
				Per 24 hours.	Per kilogram per 24 hours.	Per square meter per hour.			
Boys.	*kilos.*	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	
2½	11.5	......	....	782	68.0	....	....	......	......
6	14.5	110	....	926	63.9	....	776	+150	+19.3
6	18.4	110	....	970	52.7	....	829	+141	+17.0
7	19.2	112	....	1,067	55.6	....	844	+223	+26.4
7	20.8	110	0.79	1,153	55.4	60.8	856	+297	+34.7
9	21.8	115	0.83	1,036	47.5	52.0	881	+155	+17.6
10	30.6	131	1.05	1,338	43.7	53.1	1,075	+263	+24.6
11	26.5	129	0.98	1,151	43.4	48.9	1,002	+149	+14.9
14	36.1	142	1.20	1,310	36.3	45.5	1,179	+131	+11.1
14	36.8	142	1.21	1,285	34.9	44.3	1,188	+ 97	+ 8.2
14	43.0	149	1.34	1,525	35.5	47.4	1,309	+216	+16.5
Girls.									
6½	18.2	......	....	936	51.4	....	....	......	......
7	15.3	107	....	866	56.6	....	967	−101	−10.4
11	35.0	141	1.17	1,313	37.5	46.8	1,199	+114	+ 9.5
11	42.0	149	1.32	1,459	34.7	46.0	1,281	+178	+13.9
12	24.0	129	0.94	962	40.1	42.6	1,067	−105	− 9.8
12	25.2	128	0.95	938	37.2	41.1	1,077	−139	−12.9
12	40.2	145?	1.27	1,362	33.9	44.7	....	......	......
13	31.0	138	1.10	1,217	39.3	46.1	1,146	+ 71	+ 6.2
14	35.5	143	1.19	1,299	36.6	45.5	1,194	+105	+ 8.8

[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 238.

At first thought it would seem difficult to make metabolism experiments with children, especially with a child as young as 2½ years, with an apparatus using a mouthpiece. Nevertheless the results show reasonably close agreement with each other. When it is remembered that these investigations were carried out fully 20 years ago, it will be recognized that they represent a remarkable advance in the knowledge of the basal requirements of young children over that shown in the earlier studies. Singularly enough, they represent nearly the only extensive investigation in this field for a period of over 20 years. The results obtained by Magnus-Levy and Falk are practically the first data in the earlier literature which are available for comparison with modern work, although the latter requires even more stringent experimental conditions, particularly as to muscular repose and absence of food in the stomach. A recent biometric analysis[1] of the older subjects of Magnus-Levy and Falk shows that, on the whole, these subjects apparently had a somewhat higher metabolism than that of American subjects. In table 6 we have abstracted from the extensive material of Magnus-Levy and Falk the data dealing with children 14 years or younger, *i. e.*, the ages covered by our own observations.

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[1] Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., 1899, Suppbd., p. 314.

On the assumption that the age relationship is linear, Harris and Benedict[1] point out that the boys, particularly the young boys, are characterized by measurably higher metabolism than would be computed from the multiple-prediction methods. These differences are by no means so pronounced with the girls. Further discussion of this point is made on page 197.

Von Willebrand, 1907.—Von Willebrand[2] made a number of experiments with boys 9 to 14 years old. As his results are published in a somewhat inaccessible journal, they are given in some detail in table 7 herewith. The apparatus used were the respiration chamber in Helsingfors and the Pettersson-Sondén gas-analysis apparatus. The body-surface area was calculated by the Meeh formula, the constant 12.165 being used for the two youngest boys and 12.847 for the two older. The experiments were usually 24 hours long and began in the morning. All three meals of the day were taken in the apparatus; the subject went to bed in the evening about 8 or 9 o'clock and rose in the morning about 6 o'clock. In some instances the subject slept for a short time during the day.

In discussing his results, the author does not use the minimum values as reported in our table, but takes the average for the whole 24-hour period. He first discusses the normality of his children on the basis of weight, age, etc., but gives no heights for his subjects. As average weights, he uses 26 kg. for Veikko, 30.5 kg. for Viktor, 34.3 kg. for Julius, and 35.7 kg. for Silo. The average carbon-dioxide production per hour of these subjects is given as 17.9, 21.7, 20.2, and 18.6 grams, respectively. A comparison between the carbon-dioxide production of the subjects per hour while awake with that during sleep is given in table 8. Von Willebrand reports that Sondén and Tigerstedt found

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 233.

[2] von Willebrand, Finska Läkaresällskapets Handlingar, 1907, 49, p. 417.

TABLE 7.—*Metabolism of boys 9 to 14 years old (von Willebrand).*

Subject, age, and body-weight.	Carbon exhaled per 2 hours.		Time of minimum carbon exhaled.	Carbon-dioxide production per 2 hours.[2]	
	Max.[1]	Min.		Max.	Min.
	grams.	*grams.*		*grams.*	*grams.*
Veikko, 9 years: 25.9 kilos	14.96	5.37	9^{h}40^{m}p.m. to 11^{h}40^{m}p.m.	54.9	19.7
		3.25	11 40 p.m. 1 40 a.m.		11.9
		6.41	1 40 a.m. 3 40 a.m.		23.5
		7.86	3 40 a.m. 5 40 a.m.		28.8
Veikko, 9 years: 26.0 kilos	11.34	6.25	7 30 p.m. 9 30 p.m.	41.6	22.9
		2.75	9 30 p.m. 11 30 p.m.		10.1
		6.26	11 30 p.m. 1 30 a.m.		23.0
Veikko, 9 years: 25.9 kilos	18.35	6.05	9 35 p.m. 11 35 p.m.	67.3	22.2
		9.12	11 35 p.m. 1 35 a.m.		33.4
		9.37	1 35 a.m. 3 35 a.m.		34.4
		9.47	3 35 a.m. 5 35 a.m.		34.7
Veikko, 9 years: 26.0 kilos	15.13	5.80	9 30 a.m. 11 30 a.m.	55.5	21.3
		5.04	3 30 p.m. 5 30 p.m.		18.5
		6.32	9 30 p.m. 11 30 p.m.		23.2
		7.19	11 30 p.m. 1 30 a.m.		26.4
Viktor, 10 years: 30.0 kilos	16.18	9.34	6 15 p.m. 8 15 p.m.	59.3	34.2
		9.20	12 15 a.m. 2 15 a.m.		33.7
Viktor, 10 years: 30.3 kilos	16.04	9.71	11 30 a.m. 1 30 p.m.	58.8	35.6
		4.13	5 30 p.m. 7 30 p.m.		15.1
		9.48	11 30 p.m. 1 30 a.m.		34.8
		9.68	1 30 a.m. 3 30 a.m.		35.5
Viktor, 10 years: 30.8 kilos	17.12	9.74	7 30 p.m. 9 30 p.m.	62.8	35.7
		9.40	9 30 p.m. 11 30 p.m.		34.5
Viktor, 10 years: 30.8 kilos	15.38	4.64	5 30 p.m. 7 30 p.m.	56.4	17.0
		7.25	11 30 p.m. 1 30 a.m.		26.6
		6.35	1 30 a.m. 3 30 a.m.		23.3
Julius, 13 years: 34.1 kilos	15.28	4.12	1 30 a.m. 3 30 a.m.	56.0	15.1
		5.14	3 30 a.m. 5 30 a.m.		18.8
Julius, 13 years: 34.4 kilos	16.51	9.16	9 34 a.m. 11 30 a.m.	60.5	3.63
		9.36	5 30 a.m. 7 30 a.m.		34.3
Julius, 13 years: 34.4 kilos	17.60	5.85	11 30 a.m. 1 30 p.m.	64.5	21.5
		6.60	1 30 p.m. 3 30 p.m.		24.2
Silo, 14 years: 35.6 kilos	16.18	8.99	9 30 p.m. 11 30 p.m.	59.3	33.0
		9.58	11 30 p.m. 1 30 a.m.		35.1
		5.98	1 30 a.m. 3 30 a.m.		21.9
		6.22	3 30 a.m. 5 30 a.m.		22.8
		10.60	5 30 a.m. 7 30 a.m.		38.9
Silo, 14 years: 35.1 kilos	13.49	7.07	1 00 p.m. 3 00 p.m.	49.5	25.9
		9.81	7 00 p.m. 9 00 p.m.		36.0
		7.39	9 00 p.m. 11 00 p.m.		27.1
		7.98	11 00 p.m. 1 00 a.m.		29.3
		8.14	1 00 a.m. 3 00 a.m.		29.8
Silo, 14 years: 36.5 kilos	13.44	5.77	7 00 p.m. 9 00 p.m.	49.3	21.2
		5.15	11 00 p.m. 1 00 a.m.		18.9
		5.45	1 00 a.m. 3 00 a.m.		20.0

[1] In 9 cases the maximum carbon exhaled appeared in the morning hours; in 4 cases in the afternoon; in 1 case in the evening.

[2] Computed from carbon exhaled, using the factor 11/3.

the relation for the carbon-dioxide production between these two conditions to be 145 to 100. With regard to table 8, which is taken directly from von Willebrand's[1] table, it should be pointed out that in computing the values for asleep the author did not select absolute minimum values, but rather took an average representing the entire time the subject was in bed. Thus he disregards completely the wholly impossible variations in the carbon-dioxide production from period to period.

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[1] von Willebrand, *loc. cit.*, p. 462.

TABLE 8.—*Comparison of carbon-dioxide production of boys awake and asleep (von Willebrand).*

Subject.	Age.	Body-weight.	Carbon-dioxide production per hour.		Relation of awake to asleep.
			Awake.	Asleep.	
	years.	*kilos.*	*grams.*	*grams.*	
Veikko	9	25.9	24.8	11.7	212 : 100
Viktor	10	30.8	23.6	15.4	154 : 100
Julius	13	34.1	25.8	13.5	191 : 100
Silo	14	36.5	21.1	11.1	190 : 100
Average	....	....	23.8	12.9	186 : 100

This whole research is very perplexing. The differences in the carbon dioxide found in the 2-hour periods in different experiments with the same individual, presumably when he is asleep, are extraordinary. Such differences are wholly outside of our experience in the Nutrition Laboratory or at Wesleyan University. It appears as though there must be a gross experimental error, and yet Tigerstedt proves that the carbon-dioxide determinations in this apparatus ought to be accurate to within ±0.76 gram carbon dioxide.[1] If an attempt were made to use the absolute minimum figures, one would find values for the carbon-dioxide production per 2 hours on the experimental days with Veikko of 11.9, 10.1, 22.2, and 18.5 grams; with Viktor, 33.8, 15.2, 34.5, and 17.0 grams; with Julius, 15.1, 33.6, and 21.5 grams; and with Silo, 21.9, 25.9, and 18.9 grams. These low values were not confined to any one part of the day, but varied widely as to the time they appeared.

Niemann, 1911.—Laying special emphasis upon the 24-hour metabolism of a bottle-fed baby, and employing the small Pettenkofer-Voit chamber, Niemann,[2] in Heubner's clinic, studied a male child designated as "normal," but with a body-weight somewhat low for the age. The child was studied at the age of 3½ months for 7 days, again at 5 months for 6 days, at 8 months for 6 days, and at 9 months for 17 days. Since the metabolism measurements were made for the entire 24 hours, and no subdivision can be made for the periods when asleep, values for basal metabolism are not obtainable. As an index of the total 24-hour caloric output of children, however, this experiment, along with others of the Heubner clinic and from the Kaiserin

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[1] Tigerstedt, Skand. Arch. f. Physiol., 1906, 18, p. 304.

[2] Niemann, Jahrb. f. Kinderheilk., 1911, 74, pp. 22, 237, and 650.

Auguste Victoria-Haus, are of special value. Niemann's data are reported in table 9.

TABLE 9.—*Twenty-four hour heat production of male infant studied by Niemann.*

Age.	Body-weight.	Heat (computed) per 24 hours.		Remarks.
		Per kilo.	Per sq. m.	
mos.	*kilos.*	*cals.*	*cals.*	
3½	5.12	93.0	1,556	Computed by us, using the Lissauer constant for surface, which we subsequently show is much more accurate than that of Meeh (see p. 60).
5	5.90	85.4	1,500	
8	5.57	88.6	1,526	
9	5.98	91.2	1,608	

Frank and Niemann, 1913.—A very much undernourished male child, 3 months old, was studied by Frank and Niemann[1] in a respiration chamber after being fed for 6 weeks on breast milk and again after 4 weeks' feeding with cow's milk. The results have no special interest in a study of the normal respiratory exchange of normal children.

Murlin and Hoobler, 1915.—Employing an apparatus essentially that formerly described by us, Murlin and Hoobler[2] studied some hospital cases, of which several are considered by them as perfectly normal.[3] The values computed for the minimum heat production per square meter per 24 hours, using the more accurate Lissauer method of computing, are given in table 10. From these cases and 14 previously published by us, they discuss extensively the metabolism in relation to several physiological factors.

TABLE 10.—*Minimum heat production of children per 24 hours (Murlin and Hoobler).*

Subject.	Sex.	Age.	Body-weight (without clothing).	Minimum heat production (computed) per 24 hours.	
				Per kilo.	Per sq. m. (Lissauer).
		mos.	*kilos.*	*cals.*	*cals.*
A. S.	M.	2	5.7	50.0	863
W. L.	M.	2	4.4	58.2	936
E. H.	M.	2½	4.7	63.0	1,035
E. N.	M.	3	4.1	61.5	960
M. M.	M.	5¾	6.5	61.4	1,115
C. M.	F.	10½	9.4	61.8	1,266
W. S.	M.	11–12	9.4	60.5	1,239

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[1] Frank and Niemann, Charité-Annalen, 1913, 37, p. 94.

[2] Murlin and Hoobler, Am. Journ. Diseases of Children, 1915, 9, p. 81.

[3] One of these subjects, E. N., we would exclude from consideration because of underweight; likewise, we would question considering M. M., who, according to the authors, "no doubt had an incipient tuberculous infection."

Olin, 1915.—In a study made by Olin[1] under Professor Robert Tigerstedt and published in 1915, the carbon production of boys from 9 to 19 years old was determined. The children were taken from an elementary school in Helsingfors and studied individually in 2-hour experiments, usually in the morning after a light breakfast. The subjects were not allowed to move about in the respiration chamber, but were required to sit quiet, reading. Although approximately 200 children were studied, Olin's final discussion of the results is based upon the data obtained with 162 subjects. These results, grouped according to age, are given in table 11, which shows not only the total carbon production per individual, but also the carbon production per kilogram of body-weight and per square meter of body-surface. The range in values for the carbon production on the basis of body-surface is also included in table 11, and also the percentage distribution according to age. Meeh's formula was employed in computing the body-surface, the constant 12.205 being used for boys under 13 years and 12.847 for those at and above that age. It will be seen that the carbon production per square meter of body-surface was much larger at 11 years of age than at any other age studied, and *increased* regularly as the age decreased from 18 to 11 years. In comparing her data with those of other investigators, Olin states that, as the experiments of Magnus-Levy and Falk were made with complete muscular rest and without food, these subjects were more quiet than hers, who were in

TABLE 11.—*Carbon production of boys from 9 to 19 years of age (Olin).*

No. of subjects.	Average age.	Average body-weight (without clothing).	Body-surface (Meeh).	Height.	Carbon exhaled per 2 hours.					
					Per individual.	Per kilo of body-weight	Per square meter of body-surface.			
							Average.	Range.	Percentage distribution.	
									Less than 8.5 grams.	Greater than 9.5 grams.
	yrs.	*kilos.*	*sq. m.*	*cm.*	*grams.*	*grams.*	*grams.*	*grams.*	*p. ct.*	*p. ct.*
1	19	80.0	2.385	177	18.8	0.24	7.90	7.90	......	......
7	18	65.6	2.086	176	17.6	0.27	8.48	8.31 to 8.65	57	......
9	17	55.4	1.864	170	16.2	0.29	8.66	8.52 8.80	33	22
18	16	59.2	1.948	171	17.6	0.30	9.05	8.89 9.21	50	33
19	15	52.9	1.805	165	16.8	0.31	9.13	8.97 9.29	21	42
22	14	49.6	1.726	160	15.8	0.32	9.13	8.97 9.29	41	36
26	13	43.1	1.573	154	14.4	0.34	9.22	9.08 9.36	20	46
27	12	38.1	1.396	148	13.4	0.36	9.68	9.56 9.80	15	51
14	11	36.1	1.327	143	13.4	0.37	10.14	9.92 10.36	7	71
15	10	31.5	1.217	140	11.8	0.38	9.79	9.63 9.95	......	40
4	9	35.9	1.299	139	11.6	0.32	8.60	....	......	......

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[1] Olin, Finska Läkaresällskapets Handlingar, 1915, 57, p. 1434; also Skand. Archiv. f. Physiol., 1915, 34, p. 414.

the sitting position rather than lying. She finds, also, that her values are much lower than those of Sondén and Tigerstedt. She concludes that the earlier statements that the metabolism is greater per square meter of body-surface with young individuals than with those of full growth are completely proved by her results, which show that the metabolism of boys between 10 and 18 years of age is distinctly greater per square meter of body-surface than that of full-grown adults. The metabolism is, therefore, not dependent solely upon the body-surface, but also upon the age and growth.

Hellesen, 1915.—Laying special emphasis upon the character of the diet, particularly the isodynamic relations between carbohydrates and fats, Hellesen,[1] working in the Kaiserin Auguste Victoria-Haus in Berlin, made two 3-day experiments 9 days apart, in March 1911. As is usual with experiments made in that laboratory, the child was studied for 22 hours out of 24 hours and carbon dioxide and water-vapor alone were measured. As is customary with this type of experiment, the carbon-dioxide production for special periods of quiet was not observed. Hence no basal values can be given, and the data are of special interest only in indicating the total 24-hour heat output of a child of this age. From the average of the two experiments, each of three days, it was found that in the first period the child, a male, weighing 6,684 grams, had a heat production per 24 hours of 454.6 calories, per kilogram per 24 hours of 68.0 calories, and per square meter of body-surface of 1,245 calories.[2] In the second period the weight was 6,644 grams, the heat per 24 hours 492.4 calories, per kilogram per 24 hours 74.1 calories, and per square meter per 24 hours 1,353 calories.[2]

Du Bois, 1916.—Subsequent to the classical study of Magnus-Levy and Falk and the data obtained in the Helsingfors laboratory, the next extensive investigation of the basal metabolism of young boys was reported by Du Bois.[3] Using the respiration calorimeter, he studied the carbon-dioxide output, oxygen intake, and direct calorimetry of eight boys from 12 years 2 months to 13 years 11 months. For the purpose of obtaining further data regarding the relationship between body-surface and metabolism, the surface areas of the subjects were measured by the Du Bois linear formula. So far as the number of subjects is concerned, the experimental plan was very satisfactory, but only one experiment was made with each subject, this usually consisting of two successive 1-hour periods. Du Bois's own figures seem to indicate the futility of this method of experimentation, for they show the following variations in the heat-production per square meter per hour for six of the subjects studied: J.D.D.B.,

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[1] Hellesen, Nord. Med. Arkiv, 1915, 48, Nos. 14 and 18.
[2] Computed by us, using the Lissauer formula.
[3] Du Bois, Arch. Internal Med., 1916, 17, p. 887.

12 per cent; Reg. F., 15 per cent; Harry B., 4 per cent; Raymond M., 7 per cent; Henry K., 13 per cent; and Leslie B., 25 per cent. Thus out of the eight boys whose values were used for basal averages, four show a difference of 12 or more per cent between the results obtained in the two periods. When there is a difference of but 3 or 4 per cent, an average may legitimately be used, but with variations so large as these, it is clear that one of the two periods may approach the basal metabolism and the other must be above it. Under these conditions the averaging of the values is questionable and tends to give a high value for the basal metabolism. Du Bois concludes that these boys show on the average a heat production per unit of surface area according to the Du Bois linear formula which is 25 per cent higher than the level for adults. In analyzing the figures, however, the wide variations between the results of the two periods should be borne in mind, for values differing 12 per cent or more can hardly give a satisfactory base-line. If the lower of the two values is selected to represent the base-line, this would reduce very perceptibly the average increase above the adult level. It may be questioned, therefore, whether even the lowest value represents the basal metabolism, and a second experiment on each boy to control these important findings would have been of inestimable value.

Olmstead, Barr, and Du Bois, 1918.—Recognizing the importance of studying the metabolism of young boys at about the age of puberty, Du Bois and his associates[1] repeated the series of experiments which were made with boys in 1916 to study the changes in the metabolism after two years of growth. In this series the wide variations between the two periods were eliminated, the only two subjects showing differences of 12 per cent or more being J.D.D.B. and Reg. F. The former was not included in the calculation of the basal metabolism; the latter showed a variation of 17 per cent. Since the experimental conditions apparently approached the normal, it is probably legitimate in all cases except Reg. F. to average the results of the two periods, although it is still open to question whether duplicate experiments on separate days should not have been made.

The authors note a pronounced decrease in metabolism in this second series of experiments as compared with the results of the first series, the boys when two years older showing a decrease in the metabolism of 13 per cent. If the minimum values obtained in the first series of experiments were used for the basal metabolism instead of the average of the two periods, this decrease would obviously be less. All the evidence seems to imply that the conditions under which the first experiments were made were abnormal in that the subjects had a much more irregular metabolism than would normally be expected.

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[1] Olmstead, Barr and Du Bois, Arch. Internal Med., 1918, 21, p. 621.

The pulse-rates in all instances but one showed a pronounced decrease in the second series of experiments, L. B., for example, having a pulse-rate of 88 in the first experiment and when two years older a pulse-rate of 65. It seems almost impossible to ascribe this decrease in metabolism to a difference in age of two years, and this, combined with the gross irregularities in metabolism in the two 1-hour periods in the first experiment, and pronounced alterations in the pulse-rates, makes it all the more desirable to have researches of this type include a sufficient number of observations with each subject to establish definitely the basal minimum metabolism for each individual. It is clear that the average values used by Du Bois for the first series of experiments are certainly not basal values. From the results of the second series of experiments, in which the agreement between the two periods is much more satisfactory, the authors consider that the metabolism per hour according to the Du Bois linear formula of the boys is still higher than that of the average adult, the difference being about 11 per cent for boys 14 to 15 years old.

CONTROL EXPERIMENTS AND BASAL METABOLISM.

As will be seen from the foregoing abstracts of previous investigations, the influence of both muscular activity and food was disregarded in the earlier experimental work on metabolism; consequently the values obtained in these researches were usually not strictly basal. Most of this material was collected before the importance of absolute muscular repose was sufficiently recognized by experimenters. Furthermore, ocular observations of the degree of repose were used in the earlier studies, and these are untrustworthy, since interpretations vary widely and accurate records are obtained only by the graphic method.

While these faults in technique have, in later days, been corrected in large part, greater uniformity in experimental conditions and standards should be the rule in all laboratories studying metabolism. As emphasized in a previous section (see page 2), a knowledge of the basal metabolism is very necessary, since it represents the basic requirements of the human body to which the requirements for all activities are added. According to modern conceptions of ideal studies of the basal metabolism, which require the subject to be in the post-absorptive condition (12 hours without food) and in complete muscular repose, the basal metabolism is a perfectly definite factor. Even if the values obtained are complicated by food, as in some of the earlier experiments in this study of the metabolism of children, yet the error can not be more than a maximum of 20 per cent for short periods and rarely as high as this.

The criticism has been raised that the conditions outlined for obtaining the basal metabolism are not normal conditions, but this is not true, since all humans lie quietly in bed some 8 or 10 hours each day. On the other hand, life in a respiration chamber is not normal, for the experimental periods of Sondén and Tigerstedt, and especially the 22-hour periods of Rubner, do not represent normal conditions in a child's daily existence, when he is living a more or less active and unrestricted life. This may be illustrated by comparing the daily requirement of Rubner's boys, *i. e.*, about 1,700 calories, with the food intake of the boys in Gephart's study[1] at St. Paul's School in Concord, New Hampshire, which approximated 5,000 calories. An attempt to study the requirements of the day as a whole by a 22 to 24 hour sojourn in a respiration chamber would therefore be a great mistake and a return to the standards of 25 years ago.

The only logical method for determining the child's energy requirements for a day's existence is to obtain, first, the requirement for maintenance (the basal metabolism); second, the additional energy required for sitting in a chair reading or studying; third, the energy requirement for walking; and fourth, that for running and playing or at severe work. With adults we already have much information as to the energy requirements for the first three, and may later be able to determine the enormously variable factors for the fourth requirement.

In criticizing the experiments of Sondén and Tigerstedt and others using a large respiration chamber, one should bear in mind the fact that they were not planned to study the so-called basal metabolism, for at that time the conception of basal metabolism was but imperfectly outlined in the minds of the investigators. Furthermore, Sondén and Tigerstedt definitely claim that their results were not minimum or basal. Except when the data were determined during deep sleep, the basal metabolism for these subjects was not determined, for young children as well as adults were studied under conditions of only comparative and not complete muscular repose and during the process of digestion. For a study of the general question as to whether or not there is an alteration in the metabolism per unit of weight or per unit of surface with individuals of different ages, it may be that the experimental procedure used by them would be justifiable, namely, a study of all subjects under presumably like (though certainly not basal) conditions.

Similarly, Rubner's experiments were made to determine the total metabolism during the 24-hour period and thus could not be used for basal comparison. In Rubner's observations there was a considerable amount of sleep, which tended to compensate in part, at least, for the excess activity during the waking hours. Had Rubner's results been so published as to permit the computation of the values obtained with the subject during sleep, his experiments would have contributed towards our knowledge of the basal metabolism. Magnus-Levy and Falk's results approach more nearly the modern idea of basal metabolism, for these experimenters insisted upon repose and upon absence of food.

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[1] Gephart, Boston Med. and Surg. Journ., 1917' 176, p. 17.

While it is assumed by Sondén and Tigerstedt and by other workers that the same degree of muscular activity can be approximated with children of different ages when complete muscular repose is not insisted upon, this still remains to be proved and may fairly be questioned at this time. It is quite possible that the relatively great differences in the activity of children, youths, and adults may account for the peculiar findings recorded by these several schools when an attempt is made to superimpose a definite amount of activity upon the modern standard of complete repose.

From a purely scientific standpoint, clear-cut conditions are essential for *comparative* experiments, and if one wishes to study the differences in metabolism due to differences in age or sex, and particularly for the various diseases, we must have uniform conditions. The basal condition presents especially good opportunities for such uniformity. Studies of this kind are particularly advantageous in clinical calorimetry, for most of the subjects observed would be bed-ridden or hospital patients, spending a considerable part of their time under conditions of muscular repose.

The experiments of Sondén and Tigerstedt served their special *immediate* purpose perfectly, namely, to supply knowledge regarding the carbon-dioxide production in school rooms and halls of a group of young children. Rubner's experiments on two boys served his *special* purpose, but neither series can be considered as more than *studies of metabolism under special conditions*. This likewise applies to the major part of the respiration calorimeter experiments made at Wesleyan University. Each series demonstrated its special highly important and fundamental point, but few of the experiments are useful for further comparison. The night experiments at Wesleyan University began at 1 a. m. and were ended at 7 a. m., while the subjects were still in bed, so that results were obtained almost invariably for six hours of repose. They are therefore of more general use, since the subject was asleep and quiet, with the influence of food at a minimum.

It is the duty of twentieth-century experimenters to make experiments of more than passing value. Each experiment should contribute to our fundamental basal knowledge. Each year sees an increase in the significance of normal values; an effort should therefore be made to secure normal values which will be of service not simply in the current year but for a decade. There is no excuse for present-day controls which do not meet modern requirements. Hundreds of experiments with men and women in this laboratory have shown that the post-absorptive condition and muscular repose (with graphic registration by means of a pneumograph and kymograph) are readily obtained. Conditions for normal pulse-records are thus ideal and should accompany each experiment. In other words, normal experiments should serve not only their *immediate* purpose, but should invariably contribute toward the sum of the knowledge of basal metabolism requirements of normal subjects.

We wish to enter a plea for the same degree of intelligence in planning normal control experiments, as is shown in planning the original critical experiments in every series of metabolism experiments conducted in the future. If all workers in metabolism applied this critical analysis to their own work, the accumulation of basal material would be very rapid, and the work of the several laboratories would be much more strictly comparable than at present. While it is now practically agreed by all laboratories that ideal conditions are the post-absorptive state and complete muscular repose, the question of sleep is at present debatable ground. It is impossible to insure deep sleep, but it is possible as a rule to insure wakeful repose.

HISTORY AND PLAN OF RESEARCH.

Aside from several preliminary observations at the Nutrition Laboratory, in which only the carbon-dioxide output of infants was determined, the first studies made in this series on the gaseous metabolism of young children were carried out at the Massachusetts General Hospital. A respiration laboratory was established in that institution in January 1913, and observations by a member of the Nutrition Laboratory staff were made almost daily, except during the summer months, until June 1915. The infants first used were mostly from the Out-Patient Department, but it soon became evident that data regarding the normal metabolism of young children could not be obtained with these infants, for normal, healthy children are not to be found in a hospital. These earlier observations therefore included a considerable number of underweight children and a few abnormal cases. The results of the studies, which comprised data for children under two years of age, have been reported in detail in a monograph and elsewhere.[1] The later observations at the Massachusetts General Hospital were made with new-born infants from the Boston Lying-In Hospital, their age varying from 43 minutes to 8 days. The data for 105 new-born infants have been reported in a monograph and in several journal articles.[2]

Subsequently the apparatus at the Massachusetts General Hospital was removed to the Directory for Wet-Nurses of the Boston Infants' Hospital, and studies of children, varying in age from two weeks to two years, were carried out. Conditions here were especially favorable for the collection of normal data, as the children, mostly breast-fed, were the offspring of resident normal wet-nurses, and thus represented an unusually good type of physical normality. Furthermore, the mothers were somewhat under control. As the inmates of this institution constitute a more or less floating population, a large number of babies were available for observation. It was also possible to follow the life-history of a number of the infants and make observations of their metabolism from time to time over a period of several years. Some of the children in these prolonged studies had been previously observed in the study of new-born infants. To obtain information as to the 24-hour energy requirement of young children, two 24-hour experiments were carried out. The results of these two experiments have already been briefly reported.[1]

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914. See, also, Benedict and Talbot, Am. Journ. Diseases of Children, 1912, 4, p. 129; and 1914, 8, p. 1.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915. See, also, Benedict and Talbot, Proc. Nat. Acad. Sci., 1915, 1, p. 600, and Talbot, Am. Journ. Diseases of Children, 1917, 13, p. 495.

To complete the accumulation of data on the normal metabolism of children from birth to puberty, it was necessary to obtain older children for further studies. Arrangements were therefore made, through the courtesy of Dr. Frederic H. Knight, the superintendent of the New England Home for Little Wanderers, to establish a respiration laboratory in that institution. Studies were begun in October 1917 and continued until July 1919. The observations included children of both sexes from 2 to 15 years of age.

The obtaining of successful experimental periods was very much a question of the child's mental attitude. To secure the interested cooperation of the children a system of prizes was established. Each child volunteering as a subject for an experiment received a cake of sweet chocolate and a small sum of money, varying from 5 cents to 25 cents, according to the number of experimental periods possible to be carried out and the degree of muscular repose during the experiment. In the school-room it was made a privilege and an honor for a child to act as subject in these respiration experiments; the child reported at the end of an experiment to his teacher and schoolmates what prize he had won, and in this way interest and enthusiasm were maintained without difficulty.

To obtain information regarding the actual weight and height of children of school age, for possible use in establishing a normal standard, supplementary data were collected regarding the weight and height of the pupils of a considerable number of private schools.

The results of the observations made at the Directory for Wet-Nurses and the New England Home for Little Wanderers have not yet been reported in detail,[2] and form the subject of this monograph. This report and the two monographs previously referred to give a complete summary of the results obtained in the whole research on the metabolism of children from birth to puberty.

It will be seen from the foregoing history of the research on the basal metabolism of children carried out by the Nutrition Laboratory during almost a decade that the general plan of study was to make observations on the respiratory exchange of a large number of normal children differing in sex, age, height, and weight. As the observations were made with the children under conditions of muscular repose and in many instances with no food in the stomach, the basal or minimum metabolism was secured. By a comparison of the average values obtained, the influence of age, height, weight, and sex upon the heat production could be found, normal standards derived, and the basal energy requirements determined. A sufficiently large number of children were studied to obtain reasonably complete data for all ages between birth and puberty. In addition to this general method of research, the problem of the energy requirements during the period of rapid growth in the first years of life was also studied by making observations on the same individual at intervals over a number of years. In all, 23 children were thus studied for periods of a few months to three or four years. The data gathered in this research thus provide information not only as to the energy requirements of a large number of children, but on the energy requirements of the same child at varying ages.

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[1] Talbot, Am. Journ. Diseases of Children, 1917, 14, p. 25.

[2] A preliminary report of the results was given by one of us in the Shattuck Lecture before the Massachusetts Medical Society, June 1919. See Benedict, Boston Med. and Surg. Journ., 1919, 181, p. 107; also Talbot, Am. Journ. Diseases of Children, 1919, 18, p. 229.

In our earlier publications[1] we have already acknowledged the courtesy extended to us by the Trustees of the Massachusetts General Hospital and the Boston Lying-In Hospital. We wish also to acknowledge at this point the courtesy of the Trustees of the Directory for Wet-Nurses and the Trustees of the New England Home for Little Wanderers in allowing us to carry on these investigations in their institutions. Especially do we appreciate the hearty cooperation of the superintendent of the latter institution, Dr. Frederic H. Knight. Many of the observations were made possible through the individual interest of Miss Mary A. Slade, a teacher at the New England Home for Little Wanderers, who was very successful in arousing the interest of the children in the work. Finally, too much credit can not be given to the technical skill, devotion, and faithfulness of Miss Alice Johnson, Mrs. Dorothy A. Peabody, and Miss Inza A. Boles.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914; Carnegie Inst. Wash. Pub. No. 233, 1915.

APPARATUS AND EXPERIMENTAL TECHNIQUE.

The observations with young children ranging in age from a few minutes after birth to puberty included records of the height, body-weight (nude), pulse-rate, body temperature (rectal), muscular activity or repose, and measurements of the gaseous metabolism. From the latter, computations were made of the respiratory quotient. A general record was also kept of the condition of the child during the observations, including such data as drowsiness, sleep, crying, etc. Measurements were likewise made of the body-surface of a considerable number of the children.

RESPIRATION APPARATUS.

The apparatus used for measuring the gaseous metabolism in the studies at the Massachusetts General Hospital has already been fully described in previous publications.[1] In this apparatus a small metal chamber, with a quickly removable cover made air-tight by a water-seal, is connected with a closed-circuit ventilating apparatus. A rotary pump in the ventilating circuit draws the air from the chamber, and forces it through absorbing vessels in which are absorbed the water and carbon dioxide given off by the subject. The air is then returned to the chamber after pure oxygen is introduced from a cylinder of the compressed gas to replace that used by the child. A spirometer in the ventilating circuit provides for expansion in the volume of air. The amount of carbon dioxide expired is measured by weighing the absorbing vessels; the amount of oxygen used is determined by metering the gas introduced into the ventilating circuit. Inside the metal chamber is a wire crib, with mattress, in which the child lies during the period of observation.

Since only the basal or minimum metabolism was desired in these studies, it was necessary to have a record of the degree of muscular repose or activity of the child to be assured of comparable conditions. While ocular observations of the general condition and activities of the child can be made through the glass window in the cover, such observations give no exact records to be used as a standard in comparisons of the metabolism measurements. The only method of obtaining reliable evidence of the presence or absence of muscular movement is by means of graphic records. Provision is made for such records in this apparatus by suspending one end of the wire crib by a spiral spring, with a small pneumograph parallel to it. By this means the movements of the crib are transmitted through rubber tubing to a tambour and small pointer outside the chamber. The adjustment is so delicate that the slightest movement of the child changes the center of gravity and a record is made by the pointer on the smoked paper of a kymograph. Even the movements of the chest-wall due to respiration are frequently indicated on the kymograph record. A straight line on the kymograph record thus shows that the child is absolutely quiet.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 32; Am. Journ. Diseases of Children, 1914, 8, p. 21.

The pulse-rate is obtained with a stethoscope connected with the observer outside the chamber by rubber tubing. Records were made at intervals by the attendant nurse and show that muscular activity instantly caused an increase in the pulse-rate. Accordingly, if periods with a low pulse-rate and no activity are selected for comparison, we can be certain that the values represent the basal metabolism.

This apparatus was employed at the Massachusetts General Hospital for about two years and was also used for the observations at the Directory for Wet-Nurses, the only change being that for the older children a larger chamber was constructed. The apparatus as used in actual work at the Directory for Wet-Nurses is shown in figure 1, with assistant in charge and nurse recording the pulse-rate. The end of the chamber may be seen at the right, with the tambour and kymograph for recording the muscular activity, and connections with the nurse who is counting the pulse-rate. The ventilating system is at the left, with the carbon-dioxide absorbers and spirometer on the upper shelf of the table, and the water-absorbers and blower on the lower shelf. The gas-meter for measuring the oxygen may be seen in the center.

For the experiments at the New England Home for Little Wanderers a somewhat different form of chamber was used, *i. e.*, a small clinical respiration chamber, described in detail by Benedict and Tompkins,[1] and illustrated in figure 2. This is substantially a duplicate of the apparatus used for studying the normal infants, with the exception that the chamber is much larger and hence of a somewhat different type of construction. In that used for the infants the cover shuts down like the lid of a trunk, while in the apparatus employed for the older children the cover is of a semi-cylindrical form and is suspended by two ropes connected with a counterpoise, thus providing for raising and lowering the cover. When the cover is lowered, it enters a narrow water-seal which makes it air-tight. A rectangular window in the cover provides for illumination. Figure 2 gives a general view of the respiration laboratory at the New England Home for Little Wanderers, with the respiration chamber at the right, and the ventilating and absorbing system at the left; the kymograph and tambour appear on a small table in the background.

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[1] Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, 174, pp. 857, 898, and 939.

EXPERIMENTAL CONDITIONS.

Usually the length of the observation was determined solely by the degree of repose of the subject. When the pulse-rate had fallen to a normal level and the kymograph record showed the child was absolutely quiet, the measurements of the metabolism were begun. If a normal pulse-rate and satisfactory kymograph record could not be obtained, the observations were discontinued for that day. The measurements of the metabolism were divided into periods of 20 or 30 minutes, the number of periods usually depending upon the conditions. Since to obtain ideal conditions for measuring the basal metabolism there must be no food in the stomach, the measurements were made in this way whenever possible.

With the older children, voluntary muscular control and absence of food in the stomach could usually be secured. With young infants, however, the ideal conditions for studying basal metabolism could not be obtained, particularly as to the absence of food in the stomach. In the normal physiological state, the infant has more or less food in the stomach in process of digestion. The infant's natural protection against the lack of such food is restlessness, major activity, and crying. In consequence, when we attempted to secure the post-absorptive condition, we were almost invariably confronted with the fact that we no longer had a quiet infant, that is, one in muscular repose. Of the two factors affecting basal metabolism—food and muscular activity—the latter is so much the greater that our only alternative was to allow a minimum amount of food and thus secure muscular repose.

This presence of food in the stomach during the observation contaminates our comparable data, but was an experimental condition which, for the most part, it was impossible to eliminate with our youngest subjects. Schlossmann and Murschhauser[1] attempted to study the metabolism of an infant during prolonged hunger by giving water sweetened with saccharine and salted. The influence of the hunger was that commonly observed with adults, namely, a distinct increase in acidosis. Experiments with adults have shown that acidosis stimulates metabolism, the acid unquestionably reacting upon the cells, stimulating them to greater activity. Accordingly, as set forth in an earlier publication,[2] it becomes a difficult matter to determine the exact points at which the post-absorptive condition begins and ends and hunger with stimulating acidosis begins.

While we have in a number of our experiments been obliged to allow food in the stomach during the observation, on the other hand an examination of our data shows that in most of the observations with the younger children the subjects were asleep. In other words, at

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[1] Schlossmann and Murschhauser, Biochem. Zeitschr., 1913, 56, p. 355.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 147.

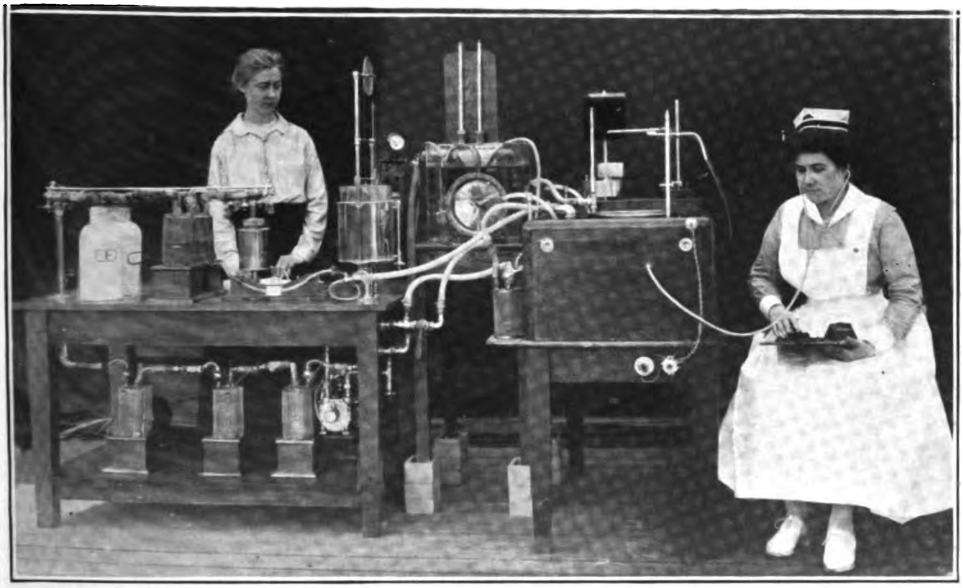

FIG. 1.—Infant respiration apparatus as used at the Directory for Wet-Nurses.

At the right are the respiration chamber, the tambour, and kymograph for recording the muscular activity, also nurse counting pulse-rate. At the left is the absorbing system, with the carbon-dioxide absorbers and spirometer on the upper shelf of the table, the water-absorbers and blower on the lower shelf. The gas-meter for measuring oxygen may be seen in center.

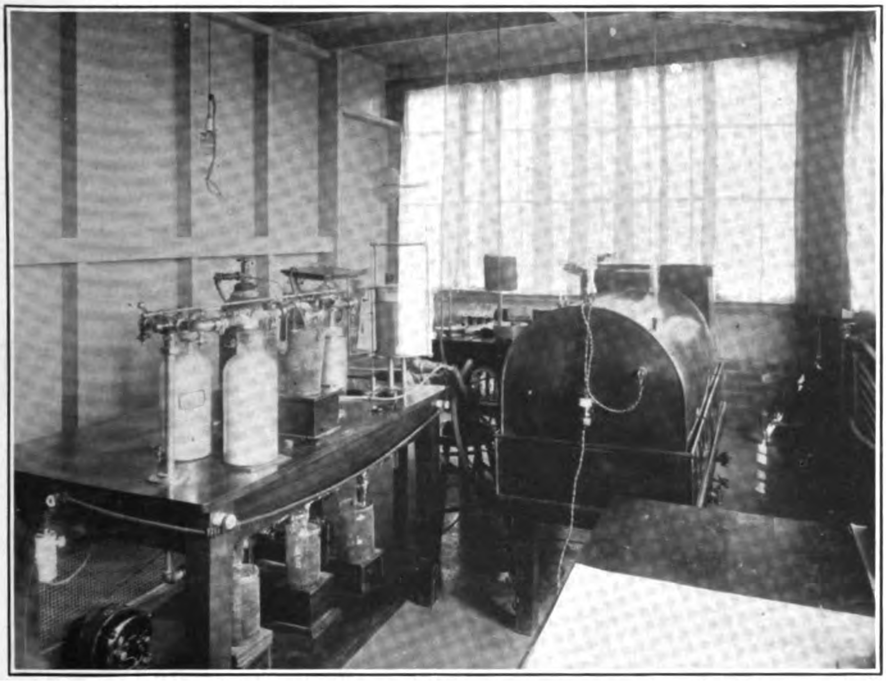

FIG. 2.—Respiration apparatus as used for children at the New England Home for Little Wanderers.

The respiration chamber, with rounded cover and thermometers, is near the center of the picture, the absorber table at the left. On the upper shelf of the table may be seen the carbon-dioxide absorbers and the spirometer; on the lower shelf are the blower and the water-absorbers. Behind the table are the large oxygen cylinder and gas-meter; the tambour and kymograph stand on a small table in the rear.

the age when it was most necessary to introduce into the metabolism measurements the stimulating factor of a small amount of food, we have the compensatory depressing influence of sleep. It is probable that these to a certain extent neutralize each other. At present, one may not exactly calculate the influence of sleep on the various children studied. Certainly, the ingestion of food on the one hand and the greater prevalence of sleep on the other tend towards a compensation which makes the measurements of the metabolism of the younger children more nearly comparable with those made with the older subjects, who were in many instances awake.

DISCUSSION OF RESULTS.

The experimental evidence accumulated in connection with this research is especially complete with regard to certain physiological measurements, particularly pulse-rate and total metabolism, with incidental observations with regard to temperature. In the final analysis of these figures the writers regret that the question of time and expense made it impossible to record simultaneously with these measurements other important physiological factors, such as blood pressure, respiration-rate, alveolar air, and alveolar carbon dioxide, for the physiology of youth needs most exhaustive study and each series of observations increases greatly in value by being associated with other physiological measurements accurately determined. It is necessary, therefore, in this discussion to lay special stress upon the rather extensive series of anthropometric measurements and the measurements of pulse-rate, rectal temperature, and particularly basal metabolism. If the total energy metabolism is looked upon as the pooled energy for the day, involving all of the various vital processes which go to make up the physical and possibly intellectual activities of the day, it can be seen that its measurement, even if at the present time incapable of subtle analysis, is of great importance. Indeed, with the accumulation of data with regard to the total energy metabolism of human individuals, it is becoming increasingly evident that this measurement is of great physiological if not indeed clinical importance.

While the number of pathological factors, other than the febrile condition, that have thus far been noted to increase metabolism above normal are relatively few, it is highly probable that subsequent studies will show deviations from the average normal metabolism produced by disease or altered conditions of nutrition. The lowering of the normal basal metabolism results from a general state of undernutrition, and hence it is perfectly consistent to say that those subjects with lowered basal metabolism are distinctly below par. Where the health of the growing child is of as great significance as it is now apparently becoming, any index of vitality is valuable. Whatever restrictions or procedures for reducing metabolism may be justifiable with overfed adults, the consensus of opinion thus far points strongly towards the necessity for a surplus of food and a high nutritive plane for the best welfare of growing children.

To throw some light upon the normal nutritive plane and to give an indication as to the general trend of the normal basal metabolism from birth through the period of early childhood are the main functions of our report. While this investigation was undertaken primarily with the idea of contributing to the abstract knowledge of the pure physiology of youth, it is gratifying to note that these results, as a natural consequence of the increased interest in the physiology of youth, have to-day a distinct practical value.

In the discussion of our findings we shall consider, first, the normality of our children as shown by the relationships between body-weight, height, and age and by the anthropometric measurements indicating growth, particularly the body-surface area, with a view to establishing, if possible, the *normal*, *average*, and *ideal* states of nutrition. We will then consider the ideal physical proportions of children, and fixing these clearly in mind, will pass to a consideration of the physiological functions with special reference to pulse-rate, rectal temperature, and particularly the gaseous exchange and total energy metabolism.

NORMALITY OF CHILDREN STUDIED.

In all of our investigations thus far on the basal metabolism of humans of both sexes and of varying ages, one of the prerequisites has been that the subjects be individuals "presumably in good health." In this stage of our study, representing the metabolism of children from birth to puberty, it seems to us particularly necessary to scrutinize the normality of the children measured. Throughout the entire investigation we held firmly in mind the idea that we were primarily interested in physiological observations and should avoid, in so far as possible, any pathological or seemingly pathological cases. Consequently, there was more or less of a natural selection, which eliminated obviously pathological cases. In the course of our investigation, however, it so happened, due either to the scarcity of subjects at the time or to the special features of an individual case, that subjects not obviously pathological were studied, who on closer scrutiny would not be considered strictly normal. It was necessary to decide arbitrarily, as we proceeded, what was and what was not physiological. No hard and fixed lines could necessarily be laid down; indeed, such lines do not exist. Ocular impressions of examining physicians, nurses, and attendants were relied upon to indicate whether or not the subject was normal. In all cases, however, there was a distinct mental reservation that before final publication the material would be thoroughly tested and only such as measured up to a reasonable estimate of normality would be included in the discussion on basal metabolism.

The dominant thought in our consideration of the question of the normality of our children is to determine what degree of success attended our efforts to eliminate incipiently pathological material from our subjects and so enable us to state with accuracy that we are dealing with the physiology of normal youth. In the first place, our own impressions of normality were substantiated by most careful physical examinations, in which always one and frequently two physicians passed critical judgment as to the normality of each child. Since this last analysis, however, must depend upon the personal judgment of the examiner, we have thought it would be highly desirable to check up the results of the physical examinations, so far as possible, by comparing the cases passed upon as normal by the physicians with some recognized standards which would be completely free from the personal equation. To the uninitiated the personal impression made by a child is always of great weight in estimating the state of normality, and one instinctively says whether a child appears well-nourished or undernourished. But age, height, and weight, as well as girths, should be taken into consideration, and it is clear that personal impressions may very likely err in estimations of this kind, and therefore should be replaced, as far as possible, by accurately determined measurements. Furthermore, it is clear that sexual differences appear at an early age, so that boys and girls may not be classed together.

At the completion of our experimental details, therefore, the selection of normal material presented a great deal of difficulty. We were instantly confronted with the question "What is normal?" While we firmly believe that all obviously abnormal children were excluded, it still remains an important point whether the general run of our children measure up to the idea of normality held by many writers. Heretofore the conception of normality has been in large part based upon the *average*, and consequently the averages selected from a large number of measurements of children of varying ages, weights, and heights have been used to indicate the *average* or *normal* growth for age, height, or weight of the child. This is not the place to define what is normal and what is average, but this point will be taken up in detail later on in this discussion.

STANDARDS FOR DETERMINING THE NORMALITY OF CHILDREN.

In considering the normality of children, special emphasis has always been laid upon the relationship between body-weight and age or between height and age, and only relatively recently between height and body-weight, irrespective of age. The age factor has always been the most important and the ratios of height to given age and body-weight to given age still remain the most commonly used criteria. At first sight this method of comparison would appear to be a relatively satisfactory one. The measurements of body-weight and of height are apparently very simple, and yet both are subject to considerable errors, particularly in the case of boys.

Weight of clothing.—For many obvious reasons, the weight of children above 5 years of age is almost invariably given with clothing.

Not infrequently the weights of children of all ages are given with clothing by various writers and an attempt is made (a very crude attempt) to correct for the clothing at the time of weighing. This method is inaccurate, since the weight of clothing varies with sex, with the seasons of the year, and with the social position of the child. Anyone can convince himself of the probable errors involved simply by emptying the pockets of a small boy. Scientifically accurate figures can therefore be obtained only when the subject is weighed naked.

Bowditch,[1] Schmid-Monnard,[2] Vierordt,[3] Griffith,[4] and other investigators have at various times reported the results of their studies of the weight of clothing worn by their subjects. In the measurements of our children we took the opportunity of studying to some extent the weight of clothing worn. Since, however, many of our children came from an institution where the clothing was more or less of uniform style and amount, our estimates of weight of clothing are not of sufficient value to record, for they may have only a local significance, a fault in common with many other series.

Another difficulty in using these two measurements of body-weight and height as standards for determining the normality of children is that usually they are taken on relatively few subjects, and for the establishment of an average or a normal value very considerable numbers of measurements of both height and body-weight at varying ages are essential. Height can and should be obtained on an indefinite number of subjects, weight also on a large number, although to be of value the weights should be nude weights. Unusual significance has been recently attached to the so-called "stem length," *i. e.*, sitting height.[5]

For greater accuracy, consideration should also be given to the amount of food eaten and the amount of water taken; the quantity of urine and feces unvoided are likewise of not inconsiderable importance. It is the present custom in physiological laboratories, where extreme accuracy is desired, to make sure, so far as possible, that food has not been taken into the stomach for several hours (usually 12) before the weight is measured, and that the bladder is emptied immediately before weighing and feces passed, if possible. It is obvious that these last refinements are with difficulty applicable to the measurement of a series of children. In our own investigations they were followed out in as many cases as possible.

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[1] Bowditch, Eighth Annual Report Mass. State Board Health, 1877, p. 275.

[2] Schmid-Monnard, Jahrb. f. Kinderheilk., 1901, 53, p. 50.

[3] Vierordt, Daten und Tabellen für Mediziner, Jena, 1906, 3 Aufl., pp. 23–24.

[4] Griffith, N. Y. Med. Journ., 1917, 106, p. 823.

[5] Walker, Proc. Roy. Soc., B, 1915, 89, p. 157; Dreyer, Lancet, Aug. 9, 1919; and von Pirquet, System der Ernährung, Berlin, 1917, p. 48.

EARLIER DATA SELECTED FOR COMPARISON WITH OUR DATA.

Employing the commonly accepted standards for normality, *i. e.*, the relationships between body-weight and age and between height and age, we have prepared four charts (figs. 3, 4, 5, and 6), on which we have placed several curves, comparing our measurements of weight and height referred to age for our laboratory children[1] with similar measurements derived from other sources. In selecting data from other sources for comparison we were influenced by the considerations outlined above relative to accuracy of measurements and number of subjects measured. Almost at the very outset it was clear to us, as has been pointed out by Holt,[2] that the difference in normal may to a great extent be one of racial characteristics and therefore that little, if any, consideration should be given to the average values of foreign writers, especially when these values deal with a very homogeneous population. For a working basis, however, for this comparison, we have chosen, first, as representing foreign children, the values from two typical foreign investigators, *i. e.*, those of Quetelet[3] and Schmid-Monnard.[4] Fortunately the fundamental and classical investigations of Bowditch[5] and the more recent studies made in an effort to implant in the American mind the importance of conserving our youth have led to the accumulation of a considerable amount of data which may be stated to be fairly representative of the American people. The more recent data, particularly that of Crum[6] and Wood,[7] have been admirably collected by Gray[8] and have been chosen by us as best representative of American children. Finally, we have also made use of measurements secured on private-school children by Holt[9] in New York City and by ourselves in private schools in the vicinity of Boston and in eastern Massachusetts.

The curves for all but our laboratory children and those of Holt were plotted from average values representing definite age-groups. Thus, the weights and heights from Quetelet, Schmid-Monnard, and Wood, as well as those of our private-school children, were averaged for each year, and those from Crum for each 6 months. The curves representing Holt's data and our own laboratory data[1] were obtained by first plotting all the numerous measurements and then drawing through the plotted points smoothed curves representing the general trend. In each case these smoothed curves are really composite curves representing the judgments of five members of the laboratory staff, who were asked to sketch in on tracing paper their visualization of the general trend.

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[1] We use the term "laboratory children" to indicate those children whose metabolism was directly studied by us in one or more of the several respiration apparatus, and to distinguish them from our group of private-school children.

[2] Holt, Am. Journ. Diseases Children, 1918, **16**, p. 359.

[3] Quetelet, Anthropométrie, Paris, 1871, pp. 177 and 346; also Sur l'homme et le développement de ses facultés, Paris, 1835, **2**, p. 46.

[4] Schmid-Monnard, Correspondensbl. d. deutsch. Gesellsch. f. Anthropol., 1900, **31**, p. 130.

[5] Bowditch, Growth of children, Public Document, Mass. State Board Health, 1877. Cited by Holt, Am. Journ. Diseases Children, 1918, **16**, p. 362.

[6] Crum, Quarterly Pub. Am. Statistical Assn., Sept. 1916, n. s., No. 115, vol. xv, Boston, pp. 332–336.

[7] Wood, personal communication to Gray.

[8] Gray and Gray, Boston Med. Surg. Journ., 1917, **177**, p. 894.

[9] Holt, Am. Journ. Diseases Children, 1918, **16**, p. 359.

While no difficulty was experienced in securing sufficient data with regard to foreign children from the classical researches of Vierordt and others, special consideration must be given the measurements of American children. One of the greatest difficulties in this connection is the fact that most of the body-weight measurements of American children, especially those above 5 years of age, include weight of clothing, and this necessitates a rather uncertain correction for clothing. In the data which we have selected, however, all measurements of body-weight, and indeed height, were taken without clothing, with one exception. Quetelet's measurements of weight involved weight of clothing, but fortunately he corrected his values for the weight of clothing worn by deducting one-eighteenth of the total weight for males and one twenty-fourth for females. Consequently we feel justified in using his values for comparison with our other data.

Of special significance is our recalculation, averaging, and charting of a series of figures compiled from the article by Gray,[2] who has very carefully made most suitable selections and who cites only body-weights without clothing. For children from 6 months to 4 years of age Gray gives values from Crum[3] which are based upon 5,602 boys and 4,821 girls. For children from 5 years to 20 years of age he gives values received by him in a personal communication from Professor Wood, of the Life Extension Institute.[4] In reporting Crum's figures, Gray quotes him as inclined to think that the children measured by him may be regarded "as somewhat super-normal, or above average," since they were measured in connection with a "better baby contest," a movement prompted by the committee on public health and instruction of the American Medical Association. The great majority of the children were of American-born parents, but were of different stocks, including German, Irish, Swedish, and some Italian. According to Crum's statement, the measurements were made upon "normal healthy children in various sections of the country"[1] and "should serve as a fair guide for many practical purposes without any additional refinements."[1] Professor Wood's measurements were made on several thousand boys and girls in the Horace Mann School, connected with Columbia University. The heights and weights were taken without clothing, but he adds the important information that the "weight of clothing ranges from about 3 pounds in five-year-old children to 6 or 7 pounds in older pupils, and is slightly greater for boys' than girls' clothing."[2] He considers that these measurements are fairly representative of healthy children in the United States.

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[1] The data for the ages, weights, and heights of our laboratory children are given in tables 26, 27, and 28 (pp. 112, 116, and 120) in our subsequent discussion of basal metabolism. Additional data for 8 boys and 4 girls, for whom basal metabolism measurements are not available but for whom we have these physical measurements, are reported in tables 12 and 13 (pp. 54 and 58) in the discussion of anthropometric measurements. As will be explained in detail later, all the individual measurements secured by us for weight, height, and age were not used in plotting these charts, but the values were averaged to a certain extent. Thus, a child was considered a new individual with an increase in age of 6 months, or with an increase in weight of 1 kg. up to 10 kg. and of 10 per cent beyond 10 kg., and measurements obtained on a child on two or three successive days or on days relatively close together were often averaged as one value rather than being used separately.

[2] Gray and Gray, Boston Med. Surg. Journ., 1917, 177, p. 894.

[3] Crum, Quarterly Pub. Am. Statistical Assn., Sept., 1916, n. s., No. 115, vol. xv, Boston, pp. 332–336. See also Gray and Gray, *loc. cit.*, p. 895, table 2.

[4] Gray and Gray, *loc. cit.*, p. 896, tables 3 and 4.

In quoting from Professor Wood, Gray very properly brings out that "a child who is short in stature for his age is apt to be under weight"[2] and that children of constant age but varying height should have different weights; but for our purpose we have taken the average value of all the weights and all the heights at the several ages, as reported by Crum and Wood, and have included them in a combined curve on our charts. It is of considerable interest to note in the several charts that there is no striking break in the curve between 4 years of age, where Crum's data end, and 5 years of age, where Wood's begin, but that the curve is reasonably regular in character. To indicate the lack of data between 4 and 5 years of age this portion of the curve has been drawn in as a broken line.

Holt's measurements were obtained on boys only, in the Browning School in New York City, a school which in his opinion represents one of the better grades of day schools in that city. In all, 1,774 observations were made "on about 350 different boys whose weights were taken semi-annually, without clothes, over a period of years, the average number of observations on each boy being five. This group of American boys, with but few exceptions, came from wealthy families and had had the advantage of good care and proper food all their lives."[3]

Our own data for private-school children represent boys and girls probably of the same social class as those measured by Holt. Records of age, height, and nude weights were made on 886 boys from eight private schools and on 323 girls in two private schools, in the neighborhood of Boston and eastern Massachusetts. Private schools were selected because the children attending them were presumably living in the most ideal home and school surroundings and should be closer to the *ideal* American in physical development than those living in less favorable surroundings.

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[1] Gray and Gray, Boston Med. Surg. Journ., 1917, 177, p. 895.

[2] Gray and Gray, *loc. cit.*, p. 897.

[3] Holt, Am. Journ. Diseases Children, 1918, 16, pp. 360 and 362.

Our laboratory children, whose measurements, together with those of our private-school children, we will now compare with the earlier data we have selected, came from a different social and economic plane of life than our private-school children. This is important to bear in mind in the following comparisons, since it has been shown many times that the development of the child depends on his social surroundings as well as upon his physical well-being. In the several charts now to be considered, since we have but a few scattered observations with our own boys beyond 13 years of age and with our own girls beyond 12 years of age, we have stopped the curves representing our measurements at 13 years for boys and at 12 years for girls.

RELATIONSHIP BETWEEN BODY-WEIGHT AND AGE WITH BOYS.

As an index of the state of nutrition of children, the relationship between body-weight and age is perhaps one of the oldest and earliest relationships which have been considered. This ratio of body-weight alone to age obviously does not take into account the very important factor of skeletal growth or length. Still, as it represents one of the earliest relationships utilized, and as it has been the basis of a large number of weight charts of various types, it requires special consideration. In figure 3, therefore, we have plotted curves for weight referred to age for boys, representing our own laboratory measurements, those in the two earlier European studies of Quetelet and Schmid-Monnard, the combined Crum-Wood data compiled by Gray, the material from Holt, and the values for the private-school boys measured under our direction.

The relative positions of these curves are of very great significance. The curves of the two foreign investigators lie throughout practically their entire length measurably below the curve for our laboratory boys, which may undoubtedly in part be explained by the fact that they represent entirely different nationalities. Between themselves they agree reasonably well. Of singular significance is the fact that the combined curve of Crum and Wood is almost identical with our laboratory curve. It is very important to note that below 4 years of age our laboratory boys measure up essentially to the standard set by this curve, although, as has been pointed out before, Crum's children are considered by him to be somewhat supernormal. A number of our children at this age were, however, the offspring of resident wet-nurses. Holt's curve for private-school boys is measurably above the line for our laboratory boys and, indeed, above the continuation of the Crum-Wood curve after the thirteenth year, while the curve for our private-school boys lies even higher than that of Holt. In the case of these private-school children we have distinctly larger and heavier boys for the same age, as is unquestionably shown by these two curves. It is important to bear in mind here that the Holt curve is derived from 1,774 measurements, while our private-school curve is based upon 886 measurements. Holt's values represent a city school, attended by children of a social status somewhat better than average, who received better medical treatment and were unquestionably living in better hygienic surroundings than the average child. Our private-school boys were likewise of a superior social status, received better medical attention, and more especially indulged in a considerable amount of active outdoor exercise, all of which factors make for a distinctly heavier boy for a given age. One of the private schools was an open-air school. The influence of outdoor life and social environment is so striking here that we have continued our curve for private-school children to the age of 18 years, at which point our collection of data ends.

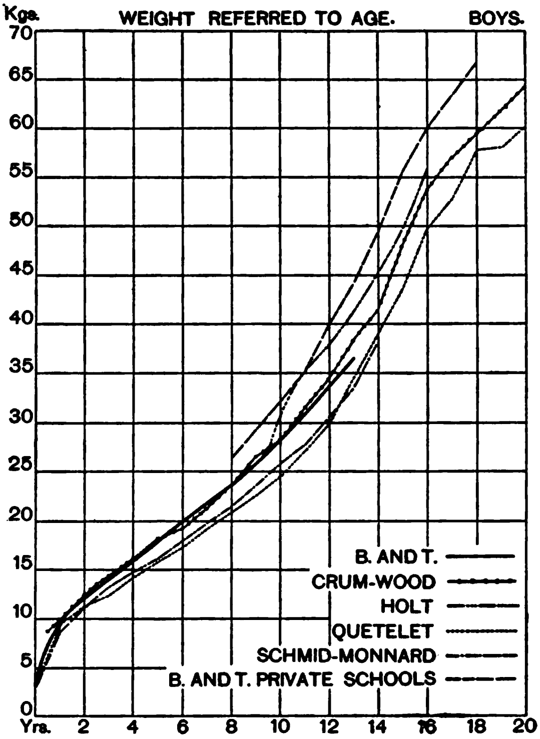

FIG. 3.—Relationship between body-weight and age with boys.

While, therefore, our curve for laboratory boys is practically identical with that of Crum and Wood and measurably higher than the curves of the foreign authorities, Quetelet and Schmid-Monnard, it is distinctly lower than the two curves for the private schools, which represent the selected classes. Since the Crum-Wood curve is derived from measurements of several thousand American children, it is clear that we may state with perfect propriety that, so far as this classic relationship of body-weight to age is concerned, our laboratory boys are *normal* as compared with the *average* American child, but are *inferior* to the *selected* class of private-school boys, who are distinctly heavier than other boys of the same age. In fact, at the age of 12 years we see that the average weight of our laboratory boys is about 34.5 kg., while the average weight of our private-school boys is about 40 kg., a very perceptibly greater weight.

RELATIONSHIP BETWEEN HEIGHT AND AGE WITH BOYS.

An intelligent understanding of the difference noted in the weight-to-age ratios of our laboratory boys and the private-school boys can not be had until we have some conception of the relative heights of these boys. Are these private-school boys heavier because they are taller, or is the weight independent of height? To answer this question we will consider next the relationship of height to age for boys, as pictured in figure 4, where we have exactly the same sets of observa-

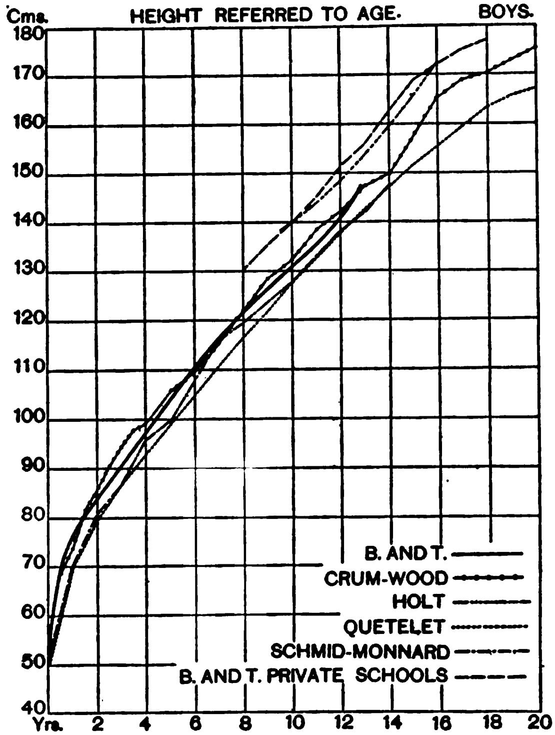

FIG. 4.—Relationship between height and age with boys.

tions used in figure 3 and exactly the same comparison will be made throughout the entire age-range. Using our own laboratory curve as the basis for comparison, we note that it lies throughout the entire length above the two foreign curves, thus indicating that our boys are consistently taller for their age than are the foreign boys. Comparing our curve, however, with the Crum-Wood curve, we see that between about 2 years and 4 years our boys are somewhat shorter than the average. From that point on the deviations in our curve above or below the Crum-Wood curve are such as to indicate for the most part uniformity between the two curves. Special attention, however, is called to that portion of the Crum-Wood curve representing the age range below 4 years, as this portion is derived from Crum's measurements, which represent "supernormal" infants. It is clear, therefore, that the average boy as measured by Crum is slightly taller for his age than are our laboratory boys; in other words, there is possibly a slight tendency for our boys to be under height, notably so at about 3 years of age.

The data for Holt's private-school boys, and likewise for our private-school boys, here again show marked superiority over the data for our laboratory boys and over the Crum-Wood average. The private-school boys, therefore, are not only heavier for their age but likewise taller. In other words, the private-school boys are, from the age of 8 years (where our study of them begins) and older, distinctly larger individuals both in height and in weight than the *average* boy of the same age.

RELATIONSHIP BETWEEN BODY-WEIGHT AND AGE WITH GIRLS.

Having examined the findings for boys, we may now consider the values for girls, first from the historic standpoint, *i. e.*, of the relationship between body-weight and age. This weight-age ratio is shown in figure 5. Fortunately, we have practically as many curves for girls as for boys and from the same sources. The Holt values, however, are missing, as Holt's study was with boys only. Our own private-school data, however, include 323 girls and are fairly representative. The line representing our laboratory studies shows that the body-weights of our girls are noticeably above those of the foreign girls until the age of 11 years is reached. At this point the Schmid-Monnard curve distinctly begins to rise above our curve. There is no suggestion of an upward trend in our curve at this point, although our data beyond 12 years are not sufficient to indicate what the further trend would be. Up to 8 years our curve lies slightly above the Crum-Wood line, which is considered to represent, for the age-range below 4 years, a rather superior order of children. After 8 years, however, it is apparent from this chart that our laboratory girls are probably somewhat under weight for their age when compared to the American average of Crum and Wood. This fact must be carefully considered in any subsequent discussion of results.

The picture exhibited by the study of boys in private schools is duplicated almost exactly here in the case of girls in private schools, where a superiority in the weight-age ratio is exhibited all along the line from 10 to 18 years of age. Clearly with girls, as with boys, this superiority may be explained either by the fact that private-school life results in the development of excessively heavy children or that the children attending private schools represent a selected class enjoying better economic conditions favoring growth.

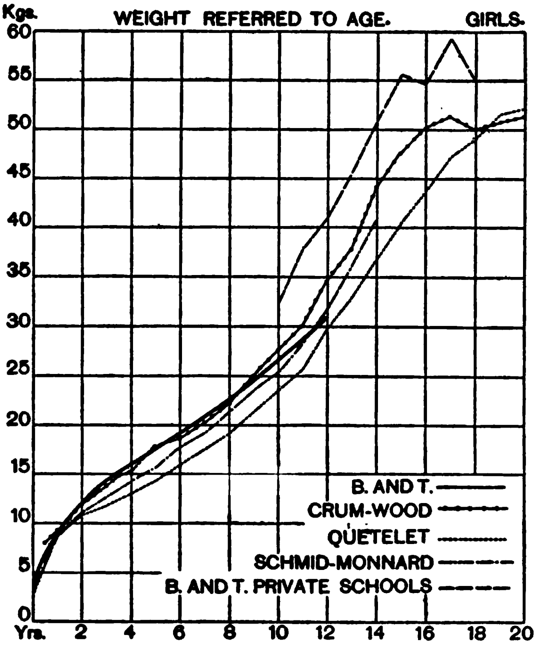

FIG. 5.—Relationship between body-weight and age with girls.

RELATIONSHIP BETWEEN HEIGHT AND AGE WITH GIRLS.

Finally, we have to consider the relationship between height and age with girls. This ratio is shown in figure 6. In this figure the curve for our laboratory girls shows that on the whole their heights are measurably above both foreign standards up to about 8 years of age, but only slightly above the Crum-Wood standard. Beyond the age of 8 years our data agree very closely with both the Schmid-Monnard and Crum-Wood series, but are perceptibly below the private-school series. While, therefore, our girls exhibit a slight underweight above 8 or 9 years of age when compared with the American average,

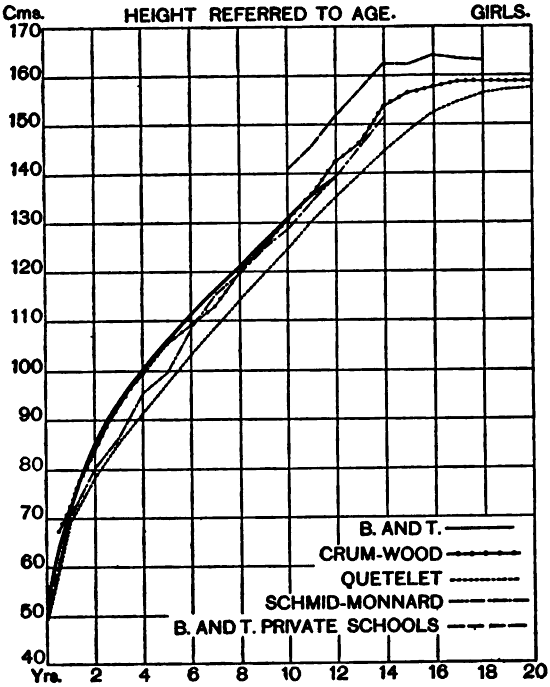

FIG. 6.—Relationship between height and age with girls.

they do not exhibit a corresponding underheight. Hence it appears (although this is not the place for discussion) that our girls were slightly under weight on the basis not only of age but likewise of height. The private-school girls, as in all the other curves where the private-school children are charted, show a clear superiority in height for age.

GENERAL CONSIDERATION OF THE RATIOS OF WEIGHT TO AGE AND HEIGHT TO AGE WITH BOYS AND GIRLS.

From figures 3, 4, 5, and 6 it appears that the data for our laboratory children agree for the most part very closely with the average values found by Crum-Wood for these ratios, and that they are in general notably above the measurements of the two foreign observers, although in the case of our girls there is inferiority in weight after the age of 8 years. The private-school data, on the other hand, both Holt's and our own, indicate superiority not only in weight for age, but likewise in height for age throughout the entire age-range studied. This speaks for a distinctly better type of youth in our private schools. It is questionable whether this is due, first, to the growth actually made in the private schools during the course of time, or to the fact that the children entering private schools come from a better class of people, from a better social economic plane, and, particularly, receive better medical care. Judged, therefore, by these old standards of height to age and weight to age, our laboratory children measure up to normal (average) in practically every instance, except in the case of the weights of our girls 8 years of age and above, but they do not measure up to the superior type of child found in the private schools in the environs of Boston.

RELATIONSHIP BETWEEN HEIGHT AND BODY-WEIGHT WITH BOYS AND GIRLS.

With adults, no one would think of considering the relationship between weight and age or height and age as of any particular significance, but, singularly enough, with children these two ratios, particularly that of weight to age, have long held the attention of physiologists to the exclusion of almost every other method of comparison. With adults, the comparison of height to weight has long been known to be a comparatively good index of the state of nutrition. If the individual is very tall and light in weight, he is obviously undernourished; if he is very short and heavy in weight, he is obese. It seems much more logical to consider the relationship between height and weight of children than between weight and age or height and age. Consequently we have plotted on our chart (fig. 7) the values representing the height referred to weight for our laboratory boys. As stated on page 37, these values for weight and height may be found

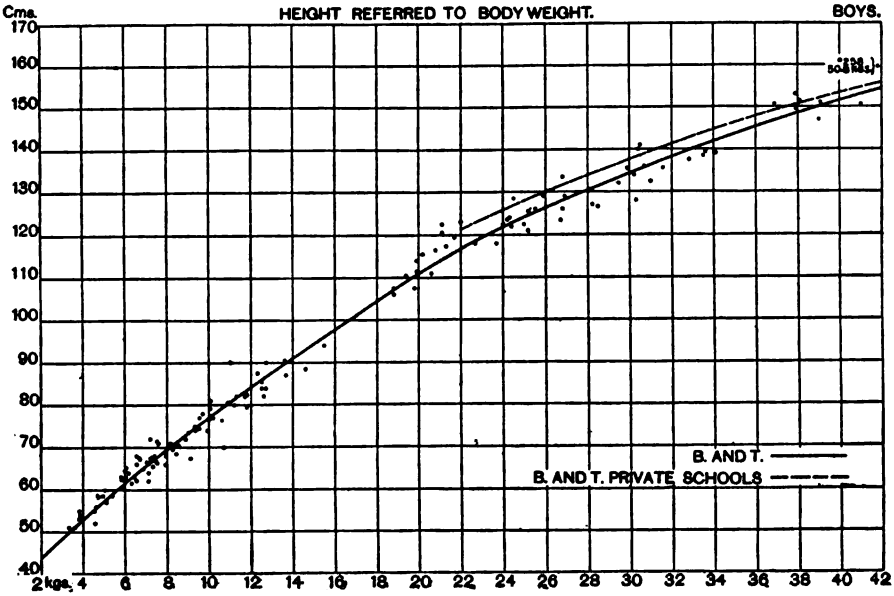

Fig. 7.—Relationship between height and body-weight with boys.

in tables 27 and 28 (pages 116 and 120) and tables 12 and 13 (pages 54 and 58); they represent, in many instances, not individual measurements, but an average of several measurements, at a particular age or weight. On this chart we have arbitrarily sketched a curve showing the general trend of this relationship, the curve (as usual) representing the personal judgments of five different individuals. It is clear from this curve that, with the subjects we have studied, a boy with a height of 110 cm. would weigh approximately 20 kg; on the other hand, a boy weighing 30 kg. would have a height of approximately 134 cm. It is especially to be emphasized that this chart does not take age into consideration, but it more nearly indicates the typical proportions of our children. Since the analysis of the earlier charts demonstrated that our children usually, both for their height *versus* age and weight *versus* age, measure up very closely with the Crum-Wood standard, it can be seen that the curve here shown on figure 7 represents not far from the probable usual height-to-weight relationship of boys.

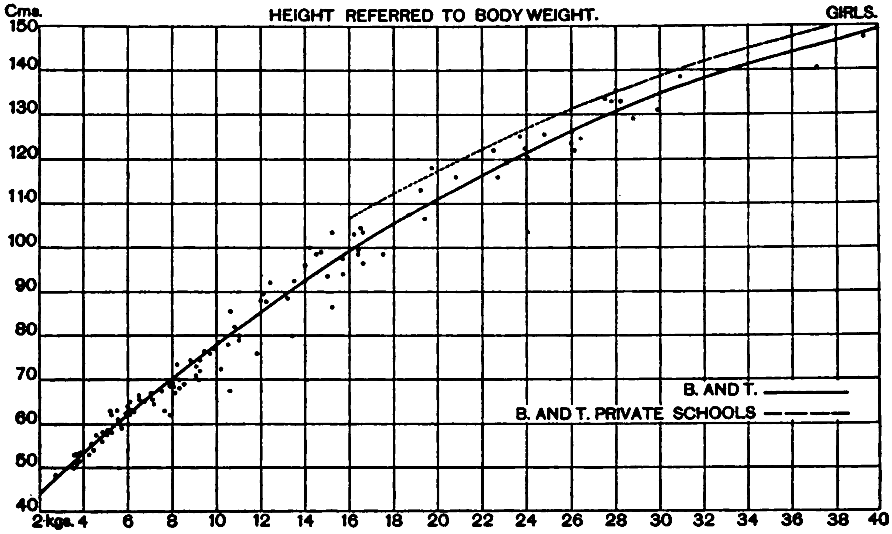

FIG. 8.—Relationship between height and body-weight with girls.

Our extensive series of measurements of private-school boys enables us to plot on our chart (fig. 7) also the smoothed curve showing the general trend of the relationship between height and weight of these boys. It is of particular interest here to note that the curve showing the relationship between height and weight of private-school boys lies at all points above that showing the height-weight ratio for our laboratory children. The conclusion is, therefore, that the private-school boys are lighter in weight for the same height than are our laboratory boys. This striking relationship will need special consideration.

If we consider the same character of data with our laboratory girls as with our boys, as plotted on figure 8, we see that the sketched line indicating the trend is in general form not unlike that obtaining for boys. Here again we have added the curve representing our private-school girls,[1] which shows, as in the case of boys, a line measurably higher at all points than the corresponding line for our laboratory girls. In other words, the private-school girls are on the average somewhat lighter in weight for the same height than are our girls.

This particular phenomenon with private-school children attracts especial attention here, since in all of our earlier comparisons on the charts indicating the ratios of height to age and weight to age it appears as if the private-school children enjoy a very marked superiority. They are taller for the same age and heavier for the same age. When, however, we compare the height to weight irrespective of age, we find that our laboratory children of both sexes are slightly heavier for the same height than are our private-school children. Thus the seeming superiority of the private-school children may to a large extent be questioned as not truly so great as at first sight appears. Our analysis has not been carried out far enough to prove whether or not there is a natural relationship between weight and height and children are heavier because they are taller. But when we consider the general configuration of children as a whole, we find that our laboratory children, both boys and girls, are somewhat heavier for the same height than are the private-school children; on this basis, therefore, it would appear that our laboratory children of both sexes are somewhat superior to the private-school children.

From the critical examination of all these data it seems clear that our laboratory children, representative as they are of the institution rather than the select home, are on the whole fully up to the best American standards based upon large series of individuals. The striking superiority in height to age and weight to age of our private-school children is in part at the sacrifice of what is commonly considered the most advantageous relationship between height and weight.

GROWTH.

The factors determining the height and weight are so subtle, especially during the years of adolescence, that they probably will require final analysis by the biometrician, but for this analysis to be effective there should be a very much larger mass of data at hand than we now possess. Under the circumstances, therefore, we can best secure an indication of the general trend of the relationships between these growth factors from our graphs and the sketched curves accompanying them. Almost immediately the fact is forced upon one that the relationships between height, weight, and age are by no means to be considered as primarily due to the age factor, but the general configuration of the body will indicate whether the child is too heavy or too light for his height. The relationships of height to weight are of most importance. This statement is not to be interpreted as meaning that the height-to-age ratio and the weight-to-age ratio should be ignored. Still, the erroneous ideas to which the consideration of the ratios of weight or height to age alone may lead one are well brought out in the discussion of our charts. Here it was shown that although the curves for the private-school children indicated apparently a great superiority over our laboratory children, a subsequent analysis of the relationship between height and weight alone proved that the superiority is by no means as great as would at first be implied, and, at least so far as the relation of height to weight is concerned, the private-school children are not superior to those of our laboratory series.

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[1] This curve for our private-school girls should properly begin at 26 kg., as the data below 26 kg. are rather limited. Nevertheless, the curve is projected below 26 kg. to 16 kg., and for this section of the curve a different style of line has been used to show that the data are, strictly speaking, insufficient between 16 and 26 kg.

The anomalous situation raised by an inspection of these charts leads at once to a consideration of the question of growth, for it is during the period from birth to puberty that we have the greatest changes in growth, both in height and in weight. Indeed, it has been stated that a young infant goes through physical changes in two or three months which it would take adults several years to equal. From the slopes of practically all of our curves it is very clear that the rate of growth is greatest during the first year of life and gradually diminishes as the child grows older. A study of a large number of measurements shows that the greatest gain in weight is made during the first 5 or 6 months of life, when a normal infant almost doubles its birth-weight. During the second 6 months of life an infant gains approximately the same amount of weight as during the first 5 or 6 months; but whereas the increase in weight during the first 5 or 6 months is 100 per cent. in the second 6 months of life it is only about 50 per cent. During the second year of life the increase in weight diminishes to approximately 25 per cent, and in the third year it is less than 20 per cent, The percentage increase in height becomes less and less with increasing age, somewhat similar to that noted for weight. Thus, the increase is about 21 per cent during the first 6 months of life, 14 per cent during the second 6 months, and correspondingly less as the child grows older. With these general principles of growth our curves conform in general, particularly the curve illustrating the weight-to-age ratio.

It must be clearly recognized at the outset that growth should not be interpreted as meaning only addition of flesh. Growth means the skeletal growth as well, and it is only by establishing the proportion between the skeletal growth and the addition of flesh that the most intelligent consideration of growth can be made. Among the numerous factors which affect growth, nationality, environment, and social status and the quantity and quality of the food are the most important. Environment and social status influence the quantity and quality of the food and also determine largely the medical care which a child receives. This latter factor in itself is becoming an increasingly important one in the element of growth, for defects in both anatomical and in dietetic conditions are recognized and corrected by early medical attention.

Influence of nationality on growth.—The well-recognized influence of nationality on growth must be taken into account in the consideration of the normality of our children. Owing to the cosmopolitan character of the American people and the large influx of European blood, nationality undoubtedly plays an important rôle in the establishment of the American standard, but for comparison with our curves the use of standard growth-curves representing nationalities other than American is, strictly speaking, precluded. Certain nations are known to be tall and well-developed, while others are typically short. Thus, the Anglo-Saxon race and certain branches of the Chinese race are pronouncedly taller than other nationalities, while the Japanese race is characteristically short. A superficial comparison of the data from different countries reveals the fact that the growth-curves for different races of men are by no means identical; indeed, this may be said to be true even for similar races inhabiting different localities. Even in Japan there are localities where the people are much taller than the general run of the inhabitants, while in England it has been found that the average weight of infants, both male and female, in London is much higher than that of infants in Leeds and slightly higher than the average weight of infants throughout the whole of England. Consequently, in comparing the growth-curves of our children with other growth-curves, emphasis has been laid upon the American data, as American data alone may properly be used in this study of normality.

Influence of environment and social status on growth.—It has been shown by various authors that environment and social status play a part in the growth of children. Those children who live much of the time out of doors and whose families can afford to supply them with good and sufficient food obtain better growth than children of the same nationality and locality who have not the same opportunities.[1] As early as 1829, Villermé[2] concluded that stature is greater and growth sooner completed, all other things being equal, in proportion as the country is richer and the comforts of the inhabitants more general. Robertson[3] reports that "increasing unfavorability of environment results in a parallel increase of deficiency in weight and stature."

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[1] Burk, Am. Journ. Psychol., 1898, 9, p. 272.

[2] Villermé, Ann. d'Hyg. Pub. et de Méd. Légale, Paris, 1829, 1, p. 351.

[3] Robertson, Am. Journ. Physiol., 1916, 41, p. 553.

He also notes that "as the favorability of the environment decreases, the proportion of medical care extended to the children, as indicated by the percentage of removed adenoids, also decreases, while the degree of medical neglect, as indicated by the percentage of infected and unoperated adenoids, undergoes a parallel increase."

Food and physical surroundings are not entirely responsible for under-growth. It has been shown that physical defects play a large part in preventing the normal growth and nourishment of children, even under good dietetic and hygienic conditions. Carious and infected teeth and enlarged and infected tonsils and adenoids are the most common physical defects responsible for under-growth and under-nourishment.

Exercise.—Ordinarily it is considered that the effect of exercise is almost immediately compensated by an increased food consumption, as commonly experienced in the ravenous appetities of vigorously exercising children, yet it may frequently happen that an underfed child automatically restricts his energy expended in work or play to a lower level, in order to provide for growth. In other words, a child that is undernourished can not supply the energy for vigorous exercise, since he needs this energy first for growth, and he will automatically cut down his activity and thus conserve energy. On the other hand, a child may be led, in the excitement of competition with his playmates, to excessive exercise. In this case the child (although furnished with a considerable amount of food) grows in height—in other words, the skeletal growth continues—but he does not gain in weight. The lack of growth in weight in this instance is due to excessive exercise and to the fact that extra food has not been added to compensate the increased muscular activity. If such a child is made to take regular rest periods during the day, he will commence to gain weight on a normal diet without an increase in the quantity of food.

The value of rest in conserving the energy of children has been most tragically illustrated in the recent experiences of German mothers in the war, as reported by Leonard Hill:[1]

> "The mothers of Germany kept their war-starved children most of the day in bed, letting them get up at 11 a. m. and go to bed at 4 p. m. Thus they husbanded the national life, taught by scientific experience that growth will make good when the war is over and food supplies become ample."

We thus see that the amount of food and exercise together play a very important part in the final resultant growth, and that while the quantity of food affects the general state of nutrition, it is not the sole cause for undernutrition. If the caloric intake is not sufficient to cover the energy output due to play and activity, the child will automatically restrict his activity so that the limited amount of food furnished will provide first for growth, primarily stature.

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[1] Hill, The science of ventilation and open-air treatment, part I, Special Report Series No. 32, Medical Research Committee, London, 1919, p. 79.

The relationship between food and height.—Too much emphasis must not be laid on the caloric value of food only. It is becoming increasingly evident that certain unidentified factors in the food, the so-called "food accessories" or popularly termed "vitamines," play a very important rôle in skeletal growth and the subsequent addition of tissue. Practically all of our knowledge of the relationship between food and height, or skeletal growth, has been obtained from observations made by the American investigators, Osborne and Mendel,[1] and McCollum,[2] on white rats. These important studies have shown that the presence in the diet of the as yet unidentified "food-accessory substances," popularly termed vitamines, is necessary to normal skeletal growth. If these "food accessories" are absent, there is a stuntage of growth in general, but development is not particularly abnormal. Osborne and Mendel were able, by the removal of these "food-accessory substances" from the diet, to defer the growth of white rats for a prolonged period. Subsequently, by supplying the proper foods and "food accessories," they caused these same white rats to attain normal growth without apparent impairment in condition, thus proving that the growth impulse or capacity for growth may be suppressed for a time and exercised later at a period far beyond the age at which growth usually ceases. Jackson and Stewart[3] found that although different organs in the body did not maintain their normal relative weight during inanition, after the proper food was given they resumed their natural growth and attained adequate size despite the early stunting. Retarded growth, therefore, does not necessarily mean that there can be no hope of attaining perfect adult form and function; on the contrary, when organic disease is absent, there is every reason to believe that there will be proper restitution on a correct diet.

Food deficiencies may be of two distinct kinds. First, there may be an absence of the "food-accessory substances" which promote growth; second, there may be a caloric deficiency which manifests itself chiefly in the loss of previously stored body material or in a decrease in body storage or growth in weight during the growing period. With a diet insufficient in caloric content, but in which the "food-accessory substances" are still present, skeletal growth continues and, as Waters[4] has shown, even if the diet be very much reduced and much below that required for maintenance, there will still be a long-continued skeletal growth without corresponding gain in weight. Hence it seems as if in the long run, unless children are greatly undernourished and their diet is woefully deficient in the "food-accessory substances," they will have a reasonably normal skeletal growth with increasing age. It is at this point that we note the special significance of the time-honored early consideration of the relationship of height to age. If the height is not up to that ordinarily found for the age, then we may reasonably assume that the "food-accessory substances" in the diet are deficient, unless we are dealing with an abnormal class of individuals containing a large number of foreign population of normally short stature. If the height is equal to that normally found for the age but the weight is too low for the height, we may then look for a deficiency in the caloric intake—that is, the calories ingested are not sufficient to take care of the heat output existing at the time, and while food may be ample for normal exercise, with excessive exercise there is deficiency in growth. Here we have the situation which is so popularly expressed by the statement that the boy "runs himself as thin as a rail."

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[1] Osborne and Mendel, Carnegie Inst. Wash. Pub. No. 156, 1911.

[2] McCollum, The newer knowledge of nutrition, New York, 1918.

[3] Jackson and Stewart, Am. Journ. Diseases Children, 1919, 17, p. 329.

[4] Waters, Proc. Soc. Promotion Agr. Sci., 1908, 29, p. 3.

From the foregoing consideration of the several factors affecting growth, it can be seen that a study of our growth-curves on the whole—that is, of our height-age, weight-age, and height-weight ratios—is probably involved by the question of nationality, the question of environment and social status as reflected in the food, exercise, and medical care, the question of "food-accessory substances" in the diet, and the caloric intake. Some of these questions, certainly that of nationality and medical care, are extremely difficult to consider separately. From our curves, however, certain deductions may legitimately be drawn. In the first place, we have seen that, based on the relationship of height to age and weight to age, our laboratory children as a whole, both boys and girls, measure up to the best and most representative standard of American children, *i. e.*, the data of Crum and Wood, but that in neither of these relationships do they measure up to the private-school children, either those studied by Holt or by ourselves. It appears, therefore, that the private-school children are taller and heavier for their age; but a subsequent consideration of the relationship between height and weight shows that on the whole they are a little thinner for the same height than are our children.

ANTHROPOMETRIC MEASUREMENTS AS INDICES OF GROWTH.

From a careful consideration of the various relationships between height, weight, and age we are convinced that the best ratio to indicate the normal state of nutrition is that of height to weight. Still, in a subject as important as this, it is desirable to make use of every conceivable measurement that may possibly contribute towards clarifying the problem as to what is the normal state of nutrition. Many writers have used, in addition to height and weight, typical measurements, such as the girth around the chest or the abdomen at the level of the umbilicus, the height of the subject when sitting, and other measurements. Pediatricians have not, however, accepted any of these generally. To show at a glance whether the individual is well nourished or poorly nourished we need some mathematical expression of relationship between either weight or height and one or more girths. In other words, some quantitative device is needed for confirming the personal opinion, which is only too frequently based upon superficial inspection.

For an entirely different purpose, *i. e.*, primarily to compute the body-surface of our subjects by the extremely ingenious linear formula of Du Bois,[1] we made a large number of measurements of various parts of the body. Many of these are, it is true, not those conventionally recorded by anthropometers, but a number do give indications of growth and are of general as well as special value. Of the numerous measurements required by the Du Bois linear formula, we believe we are warranted in publishing only two, namely, the circumferences at the nipples and at the hips and buttocks. Consequently, in tables 12 and 13, in addition to the age, height, and weight of each child, we have given these two circumferences.[2] These are included in our tables as much for the benefit of the future biometrician as for our own immediate use. The circumference at the umbilicus seemed to us too dependent upon accidental conditions (such as food in the stomach and gas in the intestines) to bring it into the same anthropometrical order of value as either of the other measurements, although obviously the chest measurement has its own inherent errors.

Finally, we have recorded in the last three columns of these same tables the results of our study of body-surface measurements by two different methods. The surface areas by the Du Bois linear formula were obtained primarily to throw light upon the possible relationship between body-surface and basal heat-production. While we firmly believe that this relationship has been very much overestimated and its significance certainly grossly misunderstood, it still remains a fact that as a general index of growth the body-surface may, theoretically at least, be of a somewhat higher degree of importance than the body-weight.[3]

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[1] Du Bois and Du Bois, Arch. Intern. Med., 1915, 15, p. 868.

[2] The data given in tables 12 and 13 were not used in plotting our various charts showing the relationships between age, weight, height, and body-surface (except in the case of 8 boys and 4 girls especially noted in the tables). The values in these tables represent individual measurements in every case and not average values. The selection of data for each child was made on the basis solely of an increase in body-weight of 1 kilogram. The values, therefore, differ somewhat from those for similar body measurements given in tables 26, 27, and 28 (pages 112, 116, and 120) which represent chiefly average values.

[3] For a consideration of the significance of the relationship between body-weight and the two-thirds power of the body-weight with other morphological measurements, see Dreyer and Ray, Phil. Trans., 1909–1910, 201, ser. B., p. 133; *ibid.*, Phil. Trans., 1911, 202, ser. B., p. 191; Dreyer, Ray, and Walker, Proc. Roy. Soc., 1912–1913, 86, ser. B., pp. 39 and 56. See also Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 168.

TABLE 12.—*Body-girths of boys and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. (1)	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
107	9 days	3.32	51.0	[2]33	....	....	0.222	....
108	11½ days	3.40	50.5	[2]33	....	....	.226	....
[3,4]8	11½ days	3.60	51.0	....	....	....	.234	....
106	8½ days	3.83	53.0	[2]36	....	....	.245	....
114	1 mo.	3.83	54.0	[2]34	[2]33	....	.245	....
115	1 mo.	3.83	55.0	34	30	0.243	.245	+0.82
27	8½ days	3.86	53.0	....	....	....	.246	....
6	8 days	4.54	52.0	....	....	....	.274	....
117	1½ mos.	4.54	54.0	38	33	.266	.274	+3.01
61	2 mos.	4.60	56.0	[2]38	[2]30	....	.276	....
118	1½ mos.	4.71	58.5	36	33	.278	.280	+ .72
115	2½ mos.	4.71	58.5	35	34	.271	.280	+3.32
119	1 mo. 1½ wks.	4.96	58.5	37	35	.313	.290	−7.35
137	4½ mos.	5.03	60.0	[2]40	....	....	.293	....
125	2 mos. 1 wk.	5.03	57.0	37	35	.301	.293	−2.66
124	2 mos. 1 wk.	5.09	57.0	[2]40	....	....	.295	....
132	1½ mos.	5.47	59.0	40	38	.322	.310	−3.73
133	3 mos.	5.48	61.0	39	37	.312	.310	− .64
118	3 mos. 1 wk.	5.66	61.5	39	36	.318	.317	− .31
125	3 mos. 1 wk.	5.74	60.5	39	39	.325	.320	−1.54
115	4½ mos.	5.77	63.0	38	36	.317	.321	+1.26
126	2 mos. 1½ wks.	5.79	60.0	40	40	.327	.322	−1.53
119	4 mos.	5.97	64.5	40	38	.331	.329	− .60
130	3 mos.	6.02	63.0?	....	....	....	.331	....
141	4 mos. 1 wk.	6.24	61.5	[2]38	[2]40	....	.344	....
132	3½ mos.	6.24	64.5	40	39	.340	.344	+1.18
128	2 mos. 3 wks.	6.35	61.5	[2]39	[2]41	....	.350	....
147	5 mos. 1 wk.	6.43	63.0	42	40	.390	.355	−8.97
155	6 mos. 3½ wks.	6.53	68.0	39	38	.383	.361	−5.74
148	5 mos. 1 wk.	6.55	66.0	42	42	.379	.362	−4.49
136	4 mos. 1 wk.	6.56	66.5	40	40	.356	.362	+1.69
161	7½ mos.	6.70	67.5	44	40	.395	.371	−6.08
115	7 mos. 3 wks.	6.83	65.0	41	43	.374	.378	+1.07
159	7½ mos.	7.03	66.5	41	42	.374	.389	+4.01
129	3 mos.	7.08	62.0	[2]43	....	....	.391	....
157	7 mos.	7.11	64.0?	....	....	....	.392	....
119	6 mos.	7.19	67.5	41	41	.399	.395	−1.00
153	6 mos. 1 wk.	7.20	67.0	43	41	.386	.395	+2.33
164	9 mos.	7.30	71.0	[2]43	....	....	.399	....
156	7 mos.	7.36	65.5	43	42	.426	.401	−5.87
150	6 mos.	7.45	72.0	[2]44	[2]38	....	.404	....
148	7 mos.	7.47	68.0	43	41	.394	.405	+2.79
158	7 mos.	7.48	66.5	44	44	.403	.405	+ .50
126	6 mos.	7.49	66.5	41	45	.400	.406	+1.50

[1] For values of *K* see table 14.

[2] The measurements noted are *not* part of the regular series of Du Bois linear measurements. They are entered here on the assumption that they represent measurements similar to those taken in the use of the Du Bois linear formula.

[3] The data for this subject were used in plotting the charts shown in figures 3 to 11 (pp. 40 to 66).

[4] Previously reported as O. C.; Benedict and Talbot, Am. Journ. Diseases of Children, 1914, 8, p. 1.

TABLE 12.—*Body-girths of boys and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. (1)	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
155	10 mos.	7.56	71.5	41	43	0.412	0.408	−0.97
154	6½ mos.	7.91	66.0	44	45	.434	.421	−3.00
138	4 mos. 3 wks.	7.94	68.0	43	46	.414	.422	+1.93
119	7½ mos.	8.08	70.5	43	45	.409	.427	+4.40
161	9 mos.	8.09	70.5	43	45	.419	.427	+1.91
136	6 mos.	8.19	71.0	44	41	.427	.431	+ .94
153	8 mos. 3 wks.	8.44	68.5	46	45	.435	.439	+ .92
158	11 mos. 3 wks.	8.48	70.5	45	45	.449	.441	−1.78
142	4 mos.	8.78	66.0	45	49	.442	.451	+2.04
148	8½ mos.	8.87	72.0	45	45	.435	.454	+4.37
170	10 mos.	9.20	74.0	[2]48	......	......	.466	......
149	5½ mos.	9.33	75.0?	......	......	......	.470	......
138	10 mos. 3½ wks.	9.53	74.5	46	46	.446	.476	+6.73
158	1 yr. 6 mos.	9.55	77.0	47	45	.483	.477	−1.24
148	12½ mos.	9.76	78.0	47	44	.458	.484	+5.68
168	9½ mos.	9.95	74.0	[2]46	......	......	.490	......
158	2 yrs. 1 mo.	10.0	81.0	48	44	.510	.492	−3.53
138	1 yr. 4 mos. 3½ wks.	10.1	79.5	48	46	.508	.495	−2.56
161	1 yr. 2 mos.	10.1	77.5	48	49	.509	.495	−2.75
153	1 yr. 6 mos.	10.2	77.0	48	47	.505	.498	−1.39
136	9 mos.	10.6	76.5	50	49	.509	.511	+ .39
142	8 mos. 1½ wks.	10.7	70.0	49	50	.530	.514	−3.02
161	1 yr. 4½ mos.	10.9	80.5	50	49	.542	.521	−3.87
153	2 yrs.	11.2	80.0	50	50	.553	.530	−4.16
138	1 yr. 10 mos. 3 wks.	11.3	82.0	49	49	.552	.534	−3.26
148	1 yr. 5 mos.	11.3	82.0	49	47	.521	.534	+2.50
158	2 yrs. 6 mos. 1 wk.	11.7	82.0	51	51	.541	.546	+ .92
119	1 yr. 1 mo. 3 wks.	11.7	79.5	50	52	.541	.546	+ .92
176	2 yrs. 5 mos.	12.2	87.5	53	48	.575	.562	−2.26
153	2 yrs. 4 mos. 3½ wks.	12.5	84.0	51	51	.570	.571	+ .18
175	2 yrs. 5 mos. 1 wk.	12.5	82.0	52	49	.552	.571	+3.44
158	2 yrs. 10 mos.	12.7	84.0	51	53	.562	.577	+2.67
155	2 yrs. 6 mos.	12.7	90.0	50	50	.568	.577	+1.58
119	1 yr. 6 mos.	12.7	83.5	52	54	.609	.577	−5.25
119	2 yrs. 1 mo.	13.6	90.5	52	54	.624	.604	−3.21
153	3 yrs. 2 wks.	13.9	88.5	51	52	.611	.613	+ .33
177	2 yrs. 7 mos. 2 wks.	14.6	88.5	55	52	.608	.633	+4.11
182	4 yrs.	15.4	94.0	55	55	.649	.671	+3.39
192	5 yrs. 6 mos. 3 wks.	18.8	106.0	58	57	.758	.791	+4.35
[3]207	7 yrs. 7 mos. 2 wks.	18.9	107.5	59	58	.804	.794	−1.24
186	4 yrs. 8 mos. 3 wks.	19.3	110.5	59	58	.829	.805	−2.90
194	5 yrs. 9 mos. 1 wk.	19.7	107.5	59	60	.820	.817	− .37
197	6 yrs. 9 mos. 3 wks.	19.9	114.0	57	58	.799	.822	+2.88
204	7 yrs. 2 mos.	19.9	111.5	59	60	.820	.822	+ .24
199	6 yrs. 10 mos. 2 wks.	20.2	115.5	60	57	.812	.831	+2.34
212	8 yrs. 1 mo.	20.5	120.5	61	58	.882	.839	−4.88

[1] For values of K see table 14.

[2] The measurements noted are *not* part of the regular series of Du Bois linear measurements. They are entered here on the assumption that they represent measurements similar to those taken in the use of the Du Bois linear formula.

[3] The data for this subject were used in plotting the charts shown in figures 3 to 11 (pp. 40 to 66).

TABLE 12.—*Body-girths of boys and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. (1)	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
187	5 yrs. 3 wks.	20.6	111.0	57	58	0.832	0.842	+1.20
215	8 yrs. 2½ mos.	20.7	116.5	59	61	.838	.845	+ .84
205	7 yrs. 2 mos. 1 wk.	21.3	117.5	60	60	.887	.861	−2.93
[2]213	8 yrs. 1 mo. 3½ wks.	21.5	119.5	64	57	.872	.866	− .69
201	6 yrs. 11 mos. 3½ wks.	21.8	122.5	60	59	.874	.874	±0.00
[2]200	6 yrs. 11 mos. 3 wks.	22.0	123.0	62	59	.876	.879	+ .34
[2]208	7 yrs. 8 mos.	22.6	118.0	60	64	.873	.895	+2.52
193	5 yrs. 7 mos. 3 wks.	23.7	118.0	62	64	.904	.924	+2.21
[2]231	10 yrs. 3 mos. 3 wks.	24.0	122.5	63	62	.976	.932	−4.51
[2]216	8 yrs. 4 mos. 3½ wks.	24.1	123.5	61	61	.976	.935	−4.20
201	7 yrs. 3 mos. 2½ wks.	24.2	124.0	61	62	.934	.937	+ .32
[2]226	9 yrs. 5½ mos.	24.6	122.0	62	64	.926	.948	+2.38
218	8 yrs. 6½ mos.	24.8	128.5	62	64	.953	.953	±0.00
222	9 yrs. 3½ wks.	25.0	122.5	64	63	.942	.958	+1.70
209	7 yrs. 10 mos. 1½ wks.	25.2	125.5	63	64	1.009	.968	−4.06
224	9 yrs. 3 mos. 3 wks.	25.6	126.0	63	63	1.025	.989	−3.51
202	7 yrs. 2 mos.	25.8	121.0	64	63	.939	.999	+6.39
223	9 yrs. 1 mo. 2 wks.	25.9	129.0	63	63	.991	1.004	+1.31
217	8 yrs. 6 mos.	26.6	123.5	64	65	.965	1.025	+6.22
218	9 yrs. 5½ mos.	26.8	133.5	62	66	.988	1.030	+4.25
242	11 yrs. 2 mos. 1½ wks.	26.8	126.0	65	64	.985	1.030	+4.57
211	8 yrs. 3 wks.	26.9	129.0	68	65	1.045	1.032	−1.24
232	10 yrs. 4 mos.	28.2	127.0	69	67	1.090	1.065	−2.29
228	9 yrs. 9 mos. 3 wks.	28.6	126.5	65	68	.998	1.076	+7.82
244	11 yrs. 4 mos. 1½ wks.	29.5	132.0	66	67	1.082	1.098	+1.48
253	12 yrs. 5 mos.	30.0	139.0	67	66	1.089	1.110	+1.93
235	10 yrs. 7 mos. 1 wk.	30.1	134.0	67	68	1.084	1.113	+2.68
229	9 yrs. 10 mos. 3½ wks.	30.4	128.0	70	69	1.057	1.120	+5.96
247	11 yrs. 8 mos. 1 wk.	30.5	141.0	66	67	1.153	1.123	−2.60
249	11 yrs. 11 mos. 3 wks.	30.6	135.5	68	70	1.183	1.125	−4.90
241	11 yrs. 1½ mos.	30.6	136.0	66	69	1.100	1.125	+2.27
236	10 yrs. 8½ mos.	31.3	132.5	70	70	1.103	1.142	+3.54
245	11 yrs. 5½ mos.	31.4	135.5	69	69	1.166	1.145	−1.80
240	11 yrs. 1 mo. 1 wk.	33.6	138.5	70	72	1.237	1.197	−3.23
256	12 yrs. 8½ mos.	33.7	137.5	69	71	1.224	1.200	−1.96
252	12 yrs. 3 mos. 2 wks.	34.1	139.0	69	72	1.245	1.209	−2.89
237	10 yrs. 8 mos. 3½ wks.	34.4	139.5	68	72	1.217	1.216	−0.08
246	11 yrs. 6 mos.	36.7	150.5	72	71	1.256	1.270	+1.11
243	11 yrs. 3 mos. 1½ wks.	37.9	149.5	73	75	1.256	1.298	+3.34
259	14 yrs. 1 mo.	37.9	151.5	73	75	1.341	1.298	−3.21
255	12 yrs. 8 mos.	37.9	153.0	68	76	1.303	1.298	− .38
254	12 yrs. 7 mos. 3 wks.	39.2	151.0	72	74	1.335	1.327	− .60
260	15 yrs. 1 wk.	39.2	147.0	72	74	1.303	1.327	+1.84
250	12 yrs. 1½ mos.	41.1	150.5	73	79	1.368	....	....
258	13 yrs. 8 mos.	51.1	159.5	83	83	1.493	....	....

[1] For values of K see table 14.

[2] The data for this subject were used in plotting the charts shown in figures 3 to 11 (pp. 40 to 66).

With regard to the measurement of body-surface, we must assume that the Du Bois linear formula gives the actual areas very closely. A note of caution has been sounded, however, by Du Bois,[1] who specifically states that it does not seem advisable to use this formula for infants under 2 years of age until the factors have been tested by the measurements of other infants. In working out their formula, the Du Boises used a small cadaver of a child 21 months old, weighing 6.27 kg., with a height of 73.2 cm., measured about two hours after death. They state "the subject was small for her age and had suffered from rachitis; the epiphyses at the wrists were large and the thorax was pigeon-breasted, being narrow and very deep antero-posteriorly."[2] The error in measurement by the linear formula as compared with the measurement of the cast was −2.9 per cent. We are of the opinion that, in limiting the use of their formula, weight rather than age should be the criterion, and that in the case of children the limit should be not children under 2 years of age but children under 6.27 kg. in weight. With this modification of their limit we are in full accord with the Du Boises.

It seemed to us, however, that if we computed the surface areas of our children, both by the Du Bois linear formula and by some standard formula, such as the Lissauer formula,[3] we could compare the values obtained on these two bases for children below 6.27 kg. in weight, note the agreement between the two methods, and thus estimate approximately the probability of accuracy in the linear formula for weights below 6 kg. Exactly this procedure we have carried out. We have carefully measured by the Du Bois linear formula the surface areas of 14 boys and 19 girls of weights under 6.27 kg. Comparing the areas thus measured with the areas computed by the formula proposed by Lissauer ($10.3\sqrt[3]{w^2}$), we found that with our boys there was a tendency for the area by the Lissauer formula to be slightly higher than that by the Du Bois linear formula; therefore, in estimating the body-surfaces of boys with weights of 6 kg. or less, we propose employing the formula $K\sqrt[3]{w^2}$, substituting the factor 10.0 for 10.3, in the belief that 10.0 is a more representative factor than the 10.3 used by Lissauer. This new factor of 10.0 gives results about 3 per cent lower than the Lissauer factor. Similarly, for estimating the body-surfaces of girls below 6 kg. in weight, the factor would be more nearly 10.1 on the average, rather than 10.3, that is, 1 per cent larger than the factor for boys. Accordingly, for computing surface areas of children with body-weights of 10 kg. or less, the factor would be not far from that proposed by Lissauer. This agreement between the new factors suggested by us (which were obtained by inspection of the surfaces computed by

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[1] Sawyer, Stone, and Du Bois, Arch. Intern. Med., 1916, 17, p. 855.

[2] Sawyer, Stone, and Du Bois, *loc. cit.*, p. 856.

[3] Lissauer, Jahrb. f. Kinderheilk., 1902, N. F., 58, p. 392.

TABLE 13.—*Body-girths of girls and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. (1)	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
49	3 wks.	2.84	49.0	[2]30	[2]27	....	....	....
26	10 days	3.56	50.0	....	....	....	0.235	....
111	13 days	3.57	53.0	[2]33	[2]29	....	.236	....
113	3½ wks.	3.65	53.0	34	31	0.249	.239	−4.02
2	9 days	3.70	53.0	35	....	....	.242	....
110	11 days	3.75	51.0	37	....	....	.244	....
109	11½ days	3.78	51.5	37	....	....	.245	....
123	2 mos. 1 wk.	3.85	53.5	35	33	.244	.248	+1.64
12	9 days	4.20	53.0	....	....	....	.263	....
131	3 mos.	4.34	55.5	35	34	.252	.269	+6.75
[3]121	2 mos.	4.80	58.0	[2]39	....	....	.287	....
48	1 mo. 1 wk.	4.81	56.0	[2]36	[2]33	....	.287	....
113	2½ mos.	4.88	59.5	37	36	.298	.290	−2.68
120	2 mos.	4.94	58.0	[2]36	....	....	.293	....
127	2 mos. 3½ wks.	5.03	57.5	37	35	.291	.296	+1.72
35	5 wks.	5.07	58.5	[2]39	[2]36	....	.298	....
122	2 mos. 1 wk.	5.17	58.5	38	39	.311	.301	−3.22
139	4½ mos.	5.19	63.0	38	35	.313	.302	−3.51
145	5 mos.	5.22	62.0	39	36	.304	.303	− .33
152	3 mos.	5.49	60.5	39	38	.313	.314	+ .32
48	2 mos. 3 wks.	5.54	61.0	[2]39	[2]33	....	.316	....
131	5 mos.	5.55	60.0	40	39	.312	.316	+1.28
151	6 mos.	5.64	60.0	[2]41	[2]33	....	.319	....
[3]143	5 mos. 1 wk.	5.73	59.0	39	37	.330	.323	−2.12
160	7½ mos.	5.90	62.5	40	37	.342	.329	−3.80
134	4 mos.	6.00	64.0	[2]41	....	....	.333	....
140	4 mos. 3 wks.	6.02	60.0	39	41	.319	.334	+4.70
122	3 mos. 3½ wks.	6.03	62.5	40	40	.347	.335	−3.46
113	4 mos. 3½ wks.	6.04	65.0	40	39	.335	.335	±0.00
123	6 mos. 1 wk.	6.09	63.0	41	38	.339	.338	− .29
139	6 mos. 1 wk.	6.11	65.0	40	40	.351	.339	−3.42
131	7 mos. 3 wks.	6.17	62.0	40	40	.336	.342	+1.79
135	4 mos.	6.20	63.0	[2]39	....	....	.344	....
165	8 mos. 3 wks.	6.24	63.0	42	40	.368	.346	−5.98
152	6 mos.	6.46	65.0	41	40	.363	.358	−1.38
139	7 mos.	7.00	67.0	43	43	.383	.388	+1.31
160	10 mos.	7.05	65.5	41	39	.375	.390	+4.00
35	4 mos.	7.17	64.5	[2]41	[2]46	....	.394	....
[3]169	9½ mos.	7.49	67.5	41	46	.423	.406	−4.02
163	8 mos. 1 wk.	7.63	63.0	[2]43	[2]46	....	.411	....
144	4 mos. 3½ wks.	7.80	62.0	47	48	.427	.417	−2.34
166	9 mos.	7.85	68.5	45	46	.406	.419	+3.20
162	8 mos.	8.00	69.5	[2]44	....	....	.424	....
127	9½ mos.	8.04	67.0	46	46	.414	.425	+2.66
140	1 yr. 2 mos.	8.11	68.0	46	43	.431	.428	− .70
160	1 yr. 3½ wks.	8.12	68.5	44	42	.407	.428	+5.16

[1] For values of *K* see table 14.

[2] The measurements noted are *not* part of the regular series of Du Bois linear measurements. They are entered here on the assumption that they represent measurements similar to those taken in the use of the Du Bois linear formula.

[3] The data for this subject were used in plotting the charts shown in figures 5 to 14 (pp. 43 to 68).

Table 13.—*Body-girths of girls and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. [1]	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
171	10 mos.	8.18	73.5	44	46	0.415	0.430	+3.61
139	9 mos. 1 wk.	8.26	70.0	46	48	.416	.433	+4.09
146	5 mos. 1 wk.	8.30	68.5	44	50	.425	.435	+2.35
167	9 mos. 1 wk.	8.52	69.0	45	48	.458	.442	−3.49
172	11½ mos.	8.80	74.5	45	43	.456	.452	− .88
166	1 yr. 1 mo. 1 wk.	8.97	71.5	45	47	.471	.458	−2.76
127	1 yr. 3 mos. 3½ wks.	9.02	73.0	48	48	.475	.460	−3.16
146	7 mos.	9.04	71.0	44	48	.426	.460	+7.98
145	10 mos. 1 wk.	9.19	70.0	46	48	.464	.465	+ .22
173	11½ mos.	9.19	72.0	46	47	.467	.465	− .43
171	1 yr. 2 mos. 1½ wks.	9.43	76.5	45	47	.465	.473	+1.72
144	7 mos.	9.70	65.5	49	56	.483	.482	− .21
139	1 yr. 2 mos. 3 wks.	9.74	76.0	48	48	.473	.483	+2.11
122	1 yr. 4½ mos.	9.80	76.0	49	47	.495	.485	−2.02
172	1 yr. 1 mo. 1 wk.	9.84	77.0	48	47	.503	.487	−3.18
122	1 yr. 6 mos. 3½ wks.	10.4	78.5	47	50	.522	.509	−2.49
145	11 mos. 3½ wks.	10.5	73.5	49	49	.514	.513	− .19
173	1 yr. 4 mos. 3 wks.	10.5	78.0	47	50	.520	.513	−1.35
144	9 mos.	10.6	67.5	50	57	.520	.517	− .58
171	1 yr. 9½ mos.	10.8	85.5	49	47	.496	.526	+6.05
139	1 yr. 8½ mos.	10.9	82.0	49	50	.541	.530	−2.03
174	2 yrs. 2 wks.	10.9	79.0	50	49	.536	.530	−1.12
166	1 yr. 8 mos. 3 wks.	11.0	80.0	48	48	.518	.534	+3.09
172	1 yr. 5½ mos.	11.1	79.5	49	49	.551	.537	−2.54
173	1 yr. 10 mos. 3 wks.	11.5	83.0	48	51	.536	.550	+2.61
166	2 yrs. 2 mos.	11.8	85.0	49	50	.568	.560	−1.41
145	1 yr. 2 mos.	11.8	76.0	50	54	.562	.560	− .36
171	2 yrs. 3 mos.	12.0	89.5	49	49	.573	.566	−1.22
139	2 yrs. 2½ mos.	12.3	88.0	50	51	.588	.575	−2.21
178	2 yrs. 10 mos. 3½ wks.	12.3	92.0	50	49	.608	.575	−5.43
166	2 yrs. 9½ mos.	13.2	88.5	52	51	.599	.603	+ .67
145	1 yr. 5 mos.	13.4	80.0	53	59	.621	.609	−1.93
171	2 yrs. 10 mos. 1½ wks.	13.4	95.0	51	51	.603	.609	+1.00
139	2 yrs. 6 mos. 3 wks.	13.5	92.5	55	54	.647	.612	−5.41
166	3 yrs. 4 mos. 2 wks.	14.0	92.5	50	51	.604	.627	+3.81
171	3 yrs. 3 mos. 1 wk.	14.2	100.0	51	50	.624	.633	+1.44
179	3 yrs. 8 mos.	14.5	98.5	53	54	.654	.642	−1.83
139	3 yrs. 7 mos. 1 wk.	14.7	98.0	53	55	.655	.648	−1.07
145	1 yr. 9 mos. 3 wks.	15.1	86.5	55	60	.668	.660	−1.20
190	5 yrs. 3½ mos.	15.2	103.5	53	54	.691	.663	−4.05
180	3 yrs. 10 mos. 3 wks.	15.4	93.5	53	53	.691	.669	−3.18
183	4 yrs. 3 mos. 3 wks.	15.7	97.5	53	56	.654	.677	+3.52
145	2 yrs. 4 mos.	15.8	94.0	53	56	.664	.680	+2.41
184	4 yrs. 4 mos. 1 wk.	16.2	103.0	55	56	.716	.692	−3.35
181	3 yrs. 11 mos.	16.4	98.5	55	56	.701	.697	− .57
171	4 yrs. 2 mos. 1 wk.	16.5	104.5	54	54	.681	.700	+2.79
195	6 yrs. 2½ wks.	16.7	99.5	55	56	.666	.706	+6.01
145	2 yrs. 9 mos. 3 wks.	16.7	96.5	55	58	.692	.706	+2.02
188	5 yrs. 1 mo. 1½ wks.	16.9	103.5	54	57	.736	.711	−3.40
145	3 yrs. 1 mo. 3 wks.	17.5	98.5	55	58	.700	.728	+4.00
191	5 yrs. 5½ mos.	18.7	107.5	57	58	.748	.761	+1.74

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[1] For values of *K* see table 14.

Table 13.—*Body-girths of girls and comparison of body-surfaces, as measured by the Du Bois linear formula and as computed from the formula* $K\sqrt[3]{w^2}$—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Circumference.		Body-surface.		
				At nipples.	At hips and buttocks.	Du Bois linear.	$K\sqrt[3]{w^2}$. (1)	Per cent deviation from Du Bois linear.
		kilos.	*cm.*	*cm.*	*cm.*	*sq. m.*	*sq. m.*	
206	7 yrs. 4 mos.	19.2	113.0	58	58	0.787	0.774	−1.65
[2]185	4 yrs. 8 mos. 1 wk.	19.4	106.5	58	60	.775	.780	+ .65
196	6 yrs. 5½ mos.	19.7	118.0	52	58	.816	.788	−3.43
206	8 yrs. 2 mos.	20.6	116.0	60	61	.835	.825	−1.20
189	5 yrs. 3 mos. 1 wk.	22.6	116.0	59	64	.871	.888	+1.95
220	9 yrs. 2 wks.	23.0	122.0	61	62	.933	.898	−3.75
203	7 yrs. 1 mo. 2 wks.	23.1	119.0	60	62	.881	.901	+2.27
219	8 yrs. 11 mos. 1 wk.	23.8	125.0	60	62	.890	.919	+3.26
225	9 yrs. 5 mos. 1 wk.	23.8	120.5	60	65	.908	.919	+1.21
210	8 yrs. 2 wks.	24.0	122.5	63	62	.940	.924	−1.70
227	9 yrs. 8 mos. 3 wks.	24.8	125.5	61	66	.939	.944	+ .53
221	9 yrs.	25.5	122.0	65	67	1.022	.962	−5.87
198	6 yrs. 8 mos.	26.0	124.0	62	68	.966	.974	+ .83
214	8 yrs. 2 mos.	26.0	126.0	60	68	.964	.974	+1.04
239	11 yrs.	27.5	133.5	68	70	1.089	1.012	−7.07
230	10 yrs. 3 mos.	27.6	133.0	65	70	1.055	1.014	−3.89
233	9 yrs. 2½ mos.	27.9	120.5	65	71	1.043	1.022	−2.01
238	10 yrs. 9 mos. 3½ wks.	28.0	135.5	61	68	1.047	1.024	−2.20
234	10 yrs. 5 mos. 3½ wks.	28.2	133.0	64	69	1.033	1.029	− .39
248	11 yrs. 10 mos. 3 wks.	28.5	129.0	64	69	1.034	1.036	+ .19
233	10 yrs. 5½ mos.	30.0	131.0	65	73	1.065	1.072	+ .66
251	12 yrs. 2 mos.	30.8	138.5	68	71	1.095	1.090	− .46
257	13 yrs. 3 mos. 3 wks.	36.7	140.5	68	77	1.217	1.226	+ .74
239	12 yrs. 3½ wks.	39.2	147.5	72	79	1.272	1.281	+ .71

[1] For values of *K* see table 14.

[2] The data for this subject were used in plotting the charts shown in figures 5 to 14 (pp. 43 to 68).

the Du Bois and Lissauer formulas) and the factor of 10.3 proposed by Lissauer rather strengthens us in our view that the Du Bois linear formula may be properly applied to children weighing 6.27 kg. or under.

Based upon our comparison of surface areas by the Lissauer and Du Bois linear formulas, we propose a series of constants for use in the formula, the cube root of the square of the weight multiplied by a constant factor *K*, which will give the most probable surface areas of children. This constant, *K*, varies with children of different weights and there is a slight difference between boys and girls, as shown in table 14 herewith.

In considering these constants, it will be noted that for both boys and girls up to about 10 or 15 kg. an average factor of 10.3 would not vary much more than 3 per cent from that found best fitted to the situation. Consequently, we must emphasize strongly here the accuracy of the old Lissauer formula for computing the surface area of young children. While our own measurements of the body-surface of children weighing 6 kg. or under would indicate that the factors for K are 10.0 and 10.1 for boys and girls, respectively, the Lissauer factor (10.3) is still in close agreement with our factors. This shows the complete futility of other constants formerly used, which were as high as 11.9, the constant of Meeh.[1]

TABLE 14.—*Constants for computing surface area* ($K\sqrt[3]{w^2}$).

Boys.		Girls.	
Body-weight (without clothing).	Constant.	Body-weight (without clothing).	Constant.
Up to 6 kg.	10.0	Up to 6 kg.	10.1
6 to 15 kg.	10.6	6 to 10 kg.	10.6
15 to 25 kg.	11.2	10 to 20 kg.	10.8
25 to 40 kg.	11.5	20 to 40 kg.	11.1

A close analysis of Lissauer's data has been given in earlier publications from this Laboratory.[2] The constants obtained from the measurements of children by Lissauer range from 8.92 to 12.40; but Lissauer emphasizes the fact that 10 of his 12 children were very much under weight. The factor finally selected by Lissauer as representative of normal was a value determined on a normal infant, $S-i$. While all of our own children were selected primarily from the standpoint of normality, and while the constants for children at this early age, according to our calculations, more nearly approach the factor 10.0 or 10.1, we still believe that the Lissauer factor is on the average very representative for children under 10 kg. in weight. Our factors indicate strongly that there is not a very great disproportion in the surface area with changes in body-weight under these conditions. In explaining some of the aberrant types of metabolism frequently found with atrophic children, it has been the custom to lay considerable emphasis upon the fact that there is a profound disturbance in the relationship between body-weight and body-surface with underweight children.[3] Based upon our normal measurements and a careful analysis of Lissauer's measurements, we believe that our constants are the best factors for computing the body-surface from the body-weight and that a considerable degree of emaciation in all probability does not profoundly affect the constant.

As an indication of the accuracy of these computations of surface area by the revised Lissauer formula, taking into account weight only and our several constants, we have recorded in tables 12 and 13 the areas as computed by the Du Bois linear formula and as computed using our several constants. It will be found that with a number of our children, especially at the lower weights, the Du Bois linear measurements are lacking. We believe, however, from our comparison of the areas by the two methods for the 14 boys and 19 girls under 6.27 kg. in weight, that for children at this lower weight-range the use of our constants gives the areas with a high degree of probability In the last column of the tables is indicated the percentage difference between the body-surface by the Du Bois linear formula as the base-line, and that computed by our constants. In examining the tables, it is important to note that the value of *K* changes with the sex and with the various weights, as indicated in table 14 given above.

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[1] Meeh, Zeitschr. f. Biol., 1879, 15, p. 425.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 164; see also Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 143.

[3] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 163.

From tables 12 and 13 it can be seen that the elaborate series of Du Bois measurements are no longer necessary in computing the surface areas of children—certainly not children approximating normal form—but one can compute the area, using the factors as given in table 14. For the sake of convenience we have felt it desirable to give a table for boys and girls separately, showing the surface areas based upon our several factors for each increasing kilogram in weight from 3 kg. to 40 kg. From this table the interpolations for fractions of kilograms are readily obtained. While by no means certain of the importance of the surface area, particularly in relation to metabolism measurements, we still deem it desirable to have a tabular method for securing rapidly the body-surface of children based upon the admirable linear formula of Du Bois. These surface areas, as presented in table 15, are primarily of significance as purely physical measurements.

TABLE 15.—*Estimated body-surfaces for body-weights from 3 to 40 kilograms.*

Body-weight (without clothing).	Surface[1] estimated for boys.	Surface[1] estimated for girls.	Body-weight (without clothing).	Surface[1] estimated for boys.	Surface[1] estimated for girls.	Body-weight (without clothing).	Surface[1] estimated for boys.	Surface[1] estimated for girls.
kilos.	*sq. m.*	*sq. m.*	*kilos.*	*sq. m.*	*sq. m.*	*kilos.*	*sq. m.*	*sq. m.*
3	0.208	0.210	16	0.711	0.686	29	1.086	1.048
4	.252	.255	17	.740	.714	30	1.110	1.072
5	.292	.295	18	.769	.742	31	1.134	1.095
6	.330	.333	19	.797	.769	32	1.159	1.119
7	.388	.388	20	.825	.796	33	1.183	1.142
8	.424	.424	21	.853	.845	34	1.207	1,164
9	.459	.459	22	.879	.872	35	1.230	1.188
10	.492	.492	23	.906	.898	36	1.254	1.210
11	.524	.534	24	.932	.924	37	1.277	1.233
12	.556	.566	25	.958	.949	38	1.300	1.255
13	.586	.597	26	1.009	.974	39	1.323	1.277
14	.616	.627	27	1.035	.999	40	1.345	1.298
15	.645	.657	28	1.060	1.024			

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[1] Surfaces estimated, using formula $K\sqrt[3]{w^2}$; for values of K at the different weight-ranges, see table 14.

PHYSIOLOGICAL AND ANTHROPOMETRICAL SIGNIFICANCE OF SURFACE AREA.

Studies of the body-surface measurements of children have been prompted primarily from an attempt to correlate the total heat production of children with some physical factor. The apparent discrepancy between the heat production per kilogram of body-weight and the total weight of the child at various ages early led to an effort to secure, if possible, a uniform basis for comparison of children and adults, *i. e.*, individuals of greatly differing weights, and it was believed that the heat production per unit of body-surface was much more nearly constant than the heat production based either upon the body-weight or any other factor; in fact, so constant as to represent a "physiological law." The extensive series of body-surface measurements made by us were admittedly secured primarily in connection with a study of the possible relationship between heat production and body-weight on the one hand and heat production and body-surface on the other. A recent critical analysis of the so-called "body-surface law" appearing from this laboratory[1] vitiates, we believe, to a very large degree, the significance of this "law," particularly that part of it which recognizes a causal relationship between the surface area and the heat production. Our present position on this point can be no better set forth than by repetition of an opinion expressed six years ago[2] to the effect that we believe body-surface has no significance in connection with heat production, except that it represents a general morphological law of growth.

We have, however, a series of carefully measured surface areas of children of varying ages. That these measurements are of direct physiological and anthropometrical importance is undoubtedly true. Thus, the marked changes appearing in the general configuration of the growing child as compared with the adult are familiar to all. Are these changes accompanied by disturbances in the general relationship between surface area and body-weight, or surface area and height, or surface area and age? This question can be adequately answered only by graphic presentation of our data.

RELATIONSHIP BETWEEN SURFACE AREA AND BODY-WEIGHT, HEIGHT, AND AGE WITH BOYS.

Since these surface areas are all actually measured according to the Du Bois linear formula and are not computed from the body-weight, it seems perfectly justifiable to plot them against age, height, and body-weight, and this we have done in the six following charts for both boys and girls.[3] Thus, in figure 9 we have plotted the body-surface referred to weight for our boy subjects. This curve, which represents the impressions of five members of the Laboratory staff, shows that in general the relationship between the surface area and weight is almost a linear one, particularly after the 8-kg. weight. Indeed, it can be seen that a straight-line curve would at the higher weight-levels fit as well as any more complicated order of curve. The correlation between the body-surface and weight is strikingly shown in this chart. The widest difference for a given weight is found at about the weight of 30 kg., namely, a difference of about 0.13 square meter or a maximum difference of about 12 per cent. So far as relationship between body-weight and body-surface with boys is concerned, therefore, it is clear that there are no abnormal fluctuations in the curve at any point throughout youthful life, and if there are marked changes in the configuration of the body, these must involve weight as well as surface.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 129.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 168.

[3] See tables 26, 27, and 28 (pp. 112, 116, and 120) and tables 12 and 13 (pp. 54 and 58) for data plotted on these charts. It will be noted that in 20 instances with the very young boys and in 19 instances with the very young girls the surface areas have been computed from the Lissauer formula, since the Du Bois measurements were not made in these cases. We feel justified in plotting these values on our charts, however, since we have demonstrated the remarkably close agreement between the surface-area measurements obtained by the Lissauer formula and the Du Bois linear formula for young children.

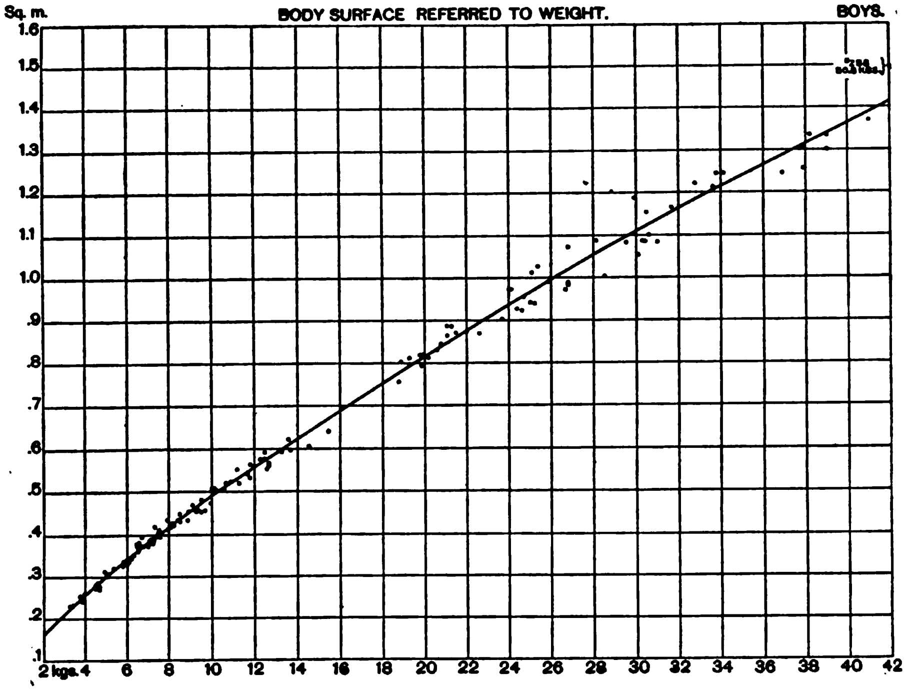

FIG. 9.—Relationship between body-surface and body-weight with boys.

In figure 10 we have plotted the measured body-surface against the height of our boys. Here, although the curve representing the general trend of the relationship is not a straight line, nevertheless it is reasonably regular throughout the entire age-range studied. The deviations either side of the curve are somewhat greater than those found in the relationship between body-surface and weight, but there is nothing to indicate an especially abnormal disturbance in the relationship between body-surface and height, although obviously there is not so close a correlation between height and body-surface as was found between weight and body-surface. Knowing the general correlation between weight and height, we may therefore infer that if there are gross changes in configuration with boys in this age-range, judged from the adult standpoint, they are not such as to disturb materially the relationship between surface area and weight or surface area and height.

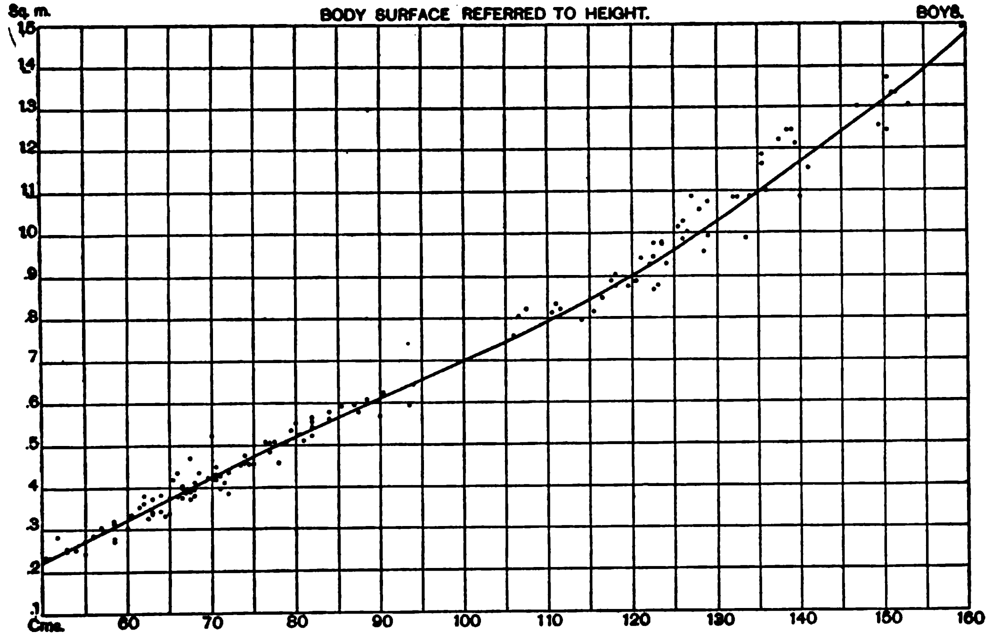

FIG. 10.—Relationship between body-surface and height with boys.

Although from the well-known correlation between height, weight, and age of children of this age-range, one would *a priori* expect a reasonably close correlation between body-surface and age, we have plotted these factors in figure 11 for our boys. As has already been noted, there is very considerable regularity in the relationship between body-surface and height and body-surface and weight, but, contrary to our expectations, in the relationship between body-surface and age we note rather striking differences, and a straight-line curve will hardly suffice here to indicate the general relationship, particularly at the youngest ages. Beyond the age of 2 years the curve is reasonably regular in form, but there are wide deviations either side at the higher age-ranges. We thus see that with boys there is a closer correlation between body-surface and weight or height than between body-surface and age. As evidence for the rather considerable changes in surface area that may actually occur in children of the same age, these points are of interest, although it is clear that age itself is not an accurate index of surface area, any more than it is an accurate index of height or weight.

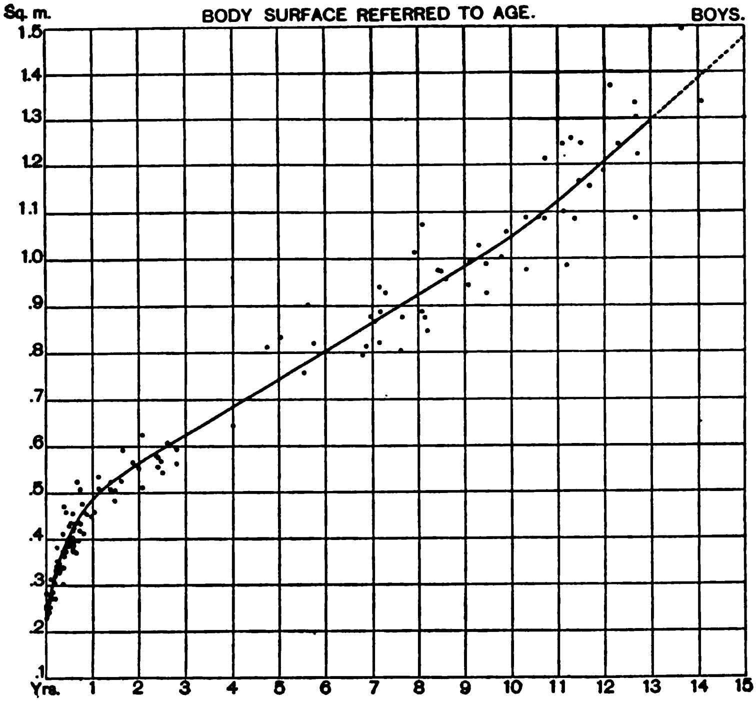

Fig. 11.—Relationship between body-surface and age with boys.

RELATIONSHIP BETWEEN SURFACE AREA AND BODY-WEIGHT, HEIGHT, AND AGE WITH GIRLS.

In figures 12, 13, and 14 we have plotted the relationships between body-surface and body-weight, body-surface and height, and body-surface and age for our girl subjects. The picture in all three instances is strikingly similar to that found for boys. The relationship between body-surface and weight is closely approximated by a straight line, although a slightly smoothed curve, as sketched on the chart, fits the situation somewhat better. No pronounced bend in this line is to be noted at any particular weight. The body-surface is not so closely correlated to height as to weight, as is seen by the somewhat wider scattering of the points about the curve sketched on figure 13. Thus, while girls of the same weight have essentially similar surface areas, girls of the same height may vary rather considerably in surface area. Perhaps the widest difference is noted with the two girls having heights of 85.5 cm. and 86.5 cm. Here the difference in height is but 1 cm., and yet there is a difference of almost 0.2 sq. m. in surface area. Finally, in the relationship between surface area and age with girls, as exhibited in the scatter diagram in figure 14, we note very wide

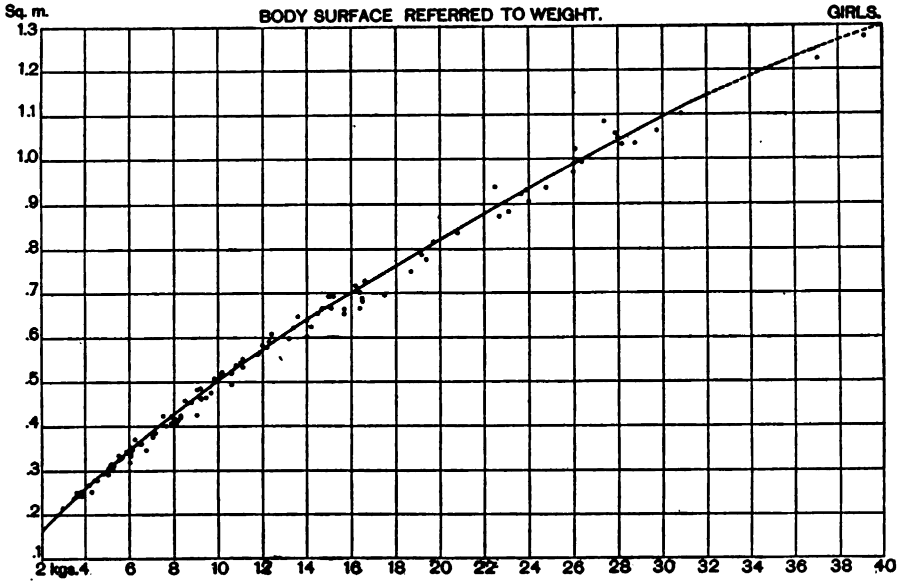

FIG. 12.—Relationship between body-surface and body-weight with girls.

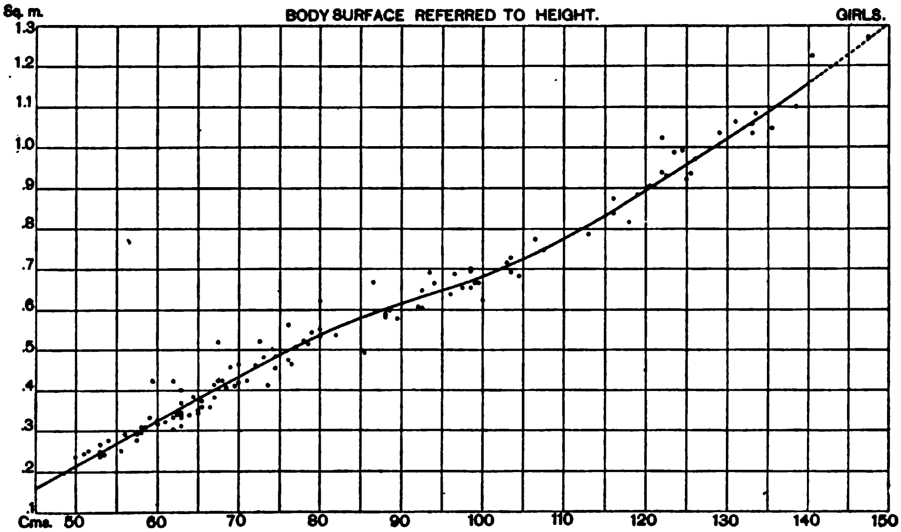

FIG. 13.—Relationship between body-surface and height with girls.

deviations from the general trend, quite similar to those found with boys, indicating again that the relationship between age and body-surface is by no means a close one. This irregularity in relationship is in large part due, we believe, to the fact that children of different ages may have markedly different weights, while children of the same weight will have essentially the same surface area, and children of the same height nearly the same surface area. At no point in figures 12, 13, or 14 is there any noticeable deviation in the line that would indicate a profound disturbance in the relationship of body-surface to either height, weight, or age.

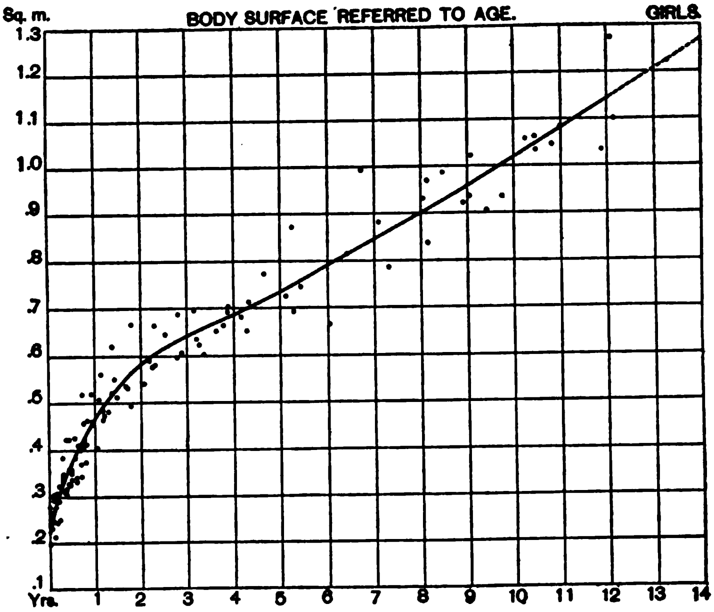

FIG. 14.—Relationship between body-surface and age with girls.

Although a further detailed analysis is out of place here, it is important that these surface areas, as actually measured, should be permanently recorded. From these charts the reader may readily pick out the individuals deviating farthest from the general line showing the relationships between body-surface and age, weight, or height, and compare them with our list of subjects in tables 12, 13, 27, and 28, where all the anthropometric data are given. It was impossible to indicate the subjects' numbers on these charts without making the charts altogether too confusing.

Owing to the earlier concept of an intimate causal relationship between body-surface and metabolism, it is important to use these carefully measured surface areas not only in reference to body-weight, height, and age, but likewise for comparison with the measured metabolism. This latter comparison is accorded treatment in the subsequent chapters of this report.

NORMAL, AVERAGE, AND IDEAL STATES OF NUTRITION.

It has long been recognized that body-weight alone referred to age may not be considered an ideal indication of the normality of the child's state of nutrition. Many investigators, in attempting to secure an index of nutritional state, have considered height as well as weight, both in reference to age, and others have added the girth of some part of the body or some power of the length. One of the most recent formulas is that suggested by Van der Loo,[1] who states that "as children grow taller they increase more proportionately in weight than in length, so that the weight divided by the square of the length gives a fairly good index for comparison of conditions in different children or in the same child at different times." For practical purposes it would be almost impossible to make direct Du Bois measurements and establish the relationship between surface area and any of the other physical factors as an index of normality of nutrition, although we have given tables (tables 14 and 15) whereby the surface area can be very closely approximated by computation based upon several constants.

Normal height.—From our earlier discussion it seems quite clear that we must consider the normal condition of the child from several bases. In the first place, what is the normal height of the child? With adults there is no such thing as normal height. The ranges of height with men and with women are very extended indeed. We form definite opinions as to whether a man is especially short or especially tall, but no one would care to state the normal height for man. The average height for a man is commonly given as 170 cm., but it is granted that there are very wide variations from this average height. With adults, then, the difference between normal and average is clearly recognized, but the average is taken as normal. Thus, the heights of a large group of individuals representing the general run of the population are measured and averaged, and this average value is considered as the normal value. We contend that this procedure is entirely erroneous when applied to children, although it is regularly employed and is a basis of most of the tables and charts in current use.

With children there should be, or at least there is properly supposed to be, a reasonably definite height for an age. It has been stated earlier in our discussion that age, weight, and height are rather closely correlated with children, in contradistinction to the situation with adults. As children grow older they increase in height and weight approximately in the same degree. It has been repeatedly shown that racial characteristics appear very prominently in height. Our American population is by no means of a pure strain, and a group of children from a large public school, especially in our big cities, may represent a large percentage of foreign blood. Under these conditions an average figure may certainly be obtained, but we believe it is not justifiable to consider this average figure as normal. From the consideration of the charts in which our private-school data were plotted (figs. 4 and 6), it is clear that the private-school children on the whole are considerably taller for their age than are our laboratory children, or, indeed, the extensive series we quote from other writers. In other words, it seems evident that the conditions obtaining with the children of private schools in eastern Massachusetts produce a greater skeletal growth, as indicated by the height. On this basis, all of these private-school children are supernormal; in other words, they are certainly above the average, and the question immediately arises, "Is the average to be considered as normal?"

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[1] Van der Loo, Nederl. Tijdschr. v. Geneesk., Amst., 1919, 1, p. 447; cited in Journ. Am. Med. Assoc., 1919, 72, p. 1403.

If one objects to the values found with the private-school children as normal values, no exception can be taken to the expression "ideal value." Hence one should compare the height and weight of a child not with the average or the fictitious normal, but with the ideal, which is unquestionably represented more nearly by our data from private schools. We wish here especially to emphasize the difference between average, normal, and ideal. When a child is short for his age this instantly indicates one of two things. In the first place, the child may be the offspring of a race of people or of parents of normally short stature; secondly, there may be a serious deficiency in the growth-producing factors in the diet. This deficiency in growth-producing factors is to be sharply distinguished from the caloric content of the diet, for it has been shown, with animals at least, that when they are maintained upon a diet of constant caloric value during the active period of growth, skeletal growth is made at the expense of the addition of tissue.

We should no longer, then, compare the height of our children to the average and call this normal. The fact that a group of 800 private-school children may attain a height for age considerably above that of the average or so-called "normal" can be taken only as an index of the fact that this *average* represents children living under conditions which do not produce the best growth. In any educational campaign for the promotion of child welfare it is important to lay special stress upon those conditions favoring the largest skeletal growth. Consequently we believe that all previous charts indicating height for age are not ideal and represent simply a group of the population that has been stunted, in part at least, by abnormal living conditions and perhaps deficient dietary constituents. In laying down this thesis we are, of course, open to the criticisms that our private-school children were less contaminated by racial commingling and that the shorter statured people did not send their children to these private schools—

in other words, that our private-school children represent the more purely typical American or Anglo-Saxon type. To a certain extent this is probably true, but we are not in a position to throw definite light upon this subject. We think it highly improbable, however, that this explanation completely accounts for the greater height of this group of children. For an estimate of the ideal height of children we believe, therefore, that one should rely not upon the so-called "normal" curve, but more nearly upon an ideal curve which is measurably higher than a normal or average commonly given. On this basis many analyses of the measurements of children which indicate that the children are above normal height simply mean that the normal level is arbitrarily adjusted at too low a point. Nutrition experts and pediatricians must hold this important relationship clearly in mind and not be content with the statement that a child is of average height when the possibilities of greater skeletal growth are presented by better living conditions, medical treatment, and general care.

Normal body-weight.—The emphasis laid upon the relationship between height and age is far overshadowed by that laid upon the relationship between body-weight and age. A child of a certain age is commonly supposed to have a certain weight, and if below this weight is considered an underweight child. As in the case of height, average weight is invariably taken as the normal weight. Normal tables or average tables have been prepared, and almost every writer combines several of the earlier series and obtains his own individual normal which he uses for his study. The very fact that this divergence and uncertainty exist in the minds of all students of the physiology of childhood shows that there has been an unwritten hesitation to accept as normal many of these values. We believe that with children certainly we should no longer consider the average as normal. With adults there are a large number of overweight individuals to compensate for the number of underweight individuals, so that the average value for body-weight represents a median line with approximately the same proportion of overweights as underweights. With children the situation is quite the reverse. The number of overweight children, even using the erroneous term "normal" when applied to the average, are much fewer than the number of underweights. On standing in front of any of our public schools and noting the condition of the children running out at the end of a day's session, one may see at a glance that the obviously overweight children are very few indeed, while those who are obviously underweight usually pass by more rapidly than they can be counted. On this ground, therefore, to take an average value for children seems wholly erroneous.

If a child is seemingly underweight for a given age, this may be due in part to his short stature—possibly a racial characteristic—

or may be due to a deficiency in the growth-promoting factors in the diet. In other words, underweight may be simply a concurrent factor with short stature, or, if the height is up to the average and the child is still noticeably underweight, this condition may be due distinctly to an insufficient caloric intake. This latter is the more probable and more common situation. If we refer again to our data for private-school children, we will recall that at all ages they were measurably heavier for their age than were the other normal series that we have reported, both our own laboratory series and the earlier standard series. As we pointed out, however, their greater weight is in large part due to their greater height. Still, the fact that outdoor environment, better medical attention, and probably better dietetic conditions have produced a larger and better conditioned child than the ordinary, especially in our public schools, is a factor that must not be overlooked.

So-called "normal weight" is not normal, but is merely average. We believe that our ideal figures, as represented in our curves for private-school children, more truly represent the normal and that pediatricians should strive for the higher weight for age as exhibited by our private-school children rather than for the average weight for age, although here again we clearly recognize the differences in nationality in mixed groups, such as those being studied in any of the public schools, and the probably purer strain of nationality in our private schools.

BODY-WEIGHT IN RELATION TO HEIGHT AS AN INDEX OF STATE OF NUTRITION.

From the foregoing discussion it is obvious that an index of the state of nutrition based on the relationships of height to age and weight to age is subject to very considerable error, because although a child may be of normally short stature with an accompanying small body-weight, due to racial characteristics, on the basis of age he would be considered to be both underheight and underweight. If the short stature is due to racial characteristics and not to deficiency in the growth-promoting factors in the diet, the child may still be considered normal, indeed may be considered ideal. Before this condition can be established, however, a far greater study of the height-weight ratio of children of normally short parents should be made, and in considering the average mixed population of American schools the element of racial characteristics must not be overlooked.

Having shown that neither an average height for age nor an average weight for age is best suited for an index of nutritional state, since the height may be accompanied by varying weights and *vice versa*, it is clear that as an index of the best proportional distribution of flesh to skeleton the relationship between height and weight is most satisfactory. For a child of a given height a definite weight is productive of a fullness of development and addition of flesh that may be termed ideal. When the child has too little flesh it is very obvious, and likewise when it has too much flesh. The problem then arises as to what is the best proportion between weight and height for children. Should children be somewhat light in build or distinctly overweight, as judged by the popular conception of underweight and overweight when applied to children? Referring again to our private-school data, we find that although these children are heavier and taller than other series of normal children at the same age, when the height and weight are compared they are on the whole somewhat thinner for their height than are our normal laboratory children selected for this study. On the basis only of weight referred to height, therefore, it would appear as if our laboratory children had somewhat the advantage over the group of private-school children, *i. e.*, so far as proportion is concerned. It still remains a fact, however, that had our laboratory children been given the advantages of private-school children, namely, outdoor life, better medical care, operative treatment if needed, and better diet, particularly with regard to growth-promoting factors, the skeletal growth would probably have been greater than actually noted.

The question is a serious one, then, as to whether we should consider a child of a certain age who has a large proportion of flesh for his height a better nourished child than one of the same age who is taller and at the same time heavier, but in whom the proportion between weight and height is not so great as with the shorter child. This question leads us to a consideration of the importance of the diet factors which play a rôle in growth. No one would seek for abnormal rapidity in the growth of children. In the normal development of the child growth proceeds with a considerable degree of regularity and, on the average, at a certain rate of rapidity. When children, however, are subjected to ideal outdoor life, with plenty of food and excellent medical care, they do grow—in skeletal form, at least, as well as in total weight—at a somewhat greater rate than otherwise. Is this desirable or not? Everything points to the desirability of this condition, and yet on close analysis it is seen that these private-school children do not have the proportion of weight to height found with the group of laboratory children selected for our measurements. Which, therefore, of the two factors is the most important in the process of growth, height or weight? The striking difference between the private-school children and our laboratory children is the greater height and correspondingly greater weight of the former, although the weight is in all probability simply a natural concomitant of the height. The fact that the obviously ideal conditions of private-school life result in this increased growth would seem to be *prima facie* evidence of its desirability. On the other hand, we must consider for a moment the relationship between weight and height which has resulted, with our laboratory children at least, in a better proportionment—that is, these children are somewhat heavier for a given height than are the private-school children.

The underweight child is a great care to nutritional experts, and so the greatest stress is laid upon the question of underweight, and apparently little, if any, attention is given to underheight. We have pointed out that underheight may be due to erroneous dietary conditions, although in many instances such conditions are perhaps entirely unsuspected. But the chief attention of all dietitians and pediatricians is given to the underweight of the child; hence, the stress laid upon the larger proportion of weight for height. The desirability of advocating this proportion is well substantiated by the importance ascribed to the relationship between weight and height in the best and recent studies of vital statistics. These statistics show clearly that longevity is better favored in youthful adults, particularly under 30 years of age, if there is a certain degree of overweight; that is, that those youths over the average weight usually have a somewhat better expectancy of life. Beyond the age of 35 years statistics show that a weight somewhat under the average insures a better life expectancy. If during the period of early adult age, longevity is favored by having the weight somewhat above the average, it seems a reasonable conclusion that this same condition must be advantageous for children. Consequently we believe that during the entire period of growth the weight should, if possible, be somewhat over the average and should approach the ideal as indicated by the weight for ages of our private-school children. Indeed, it seems logical to assume that if the private-school children had been supplied with a larger amount of food, so that they could have put on more flesh and had a proportion of weight to height more nearly in accord with that found with our laboratory children, they would have presented an even more ideal picture. Apparently they were slightly underweight for their height, while our laboratory children, selected from by no means as good an environment, showed a somewhat better proportion of weight to height—better when judged on the basis that excess weight is advantageous during the period of growth. For these reasons we believe that all curves which represent a so-called normal, either for height or for weight, are drawn at too low a level, and instead of using the average for normal, as is commonly done, a value perceptibly higher than the average should be striven for in establishing any standards to represent the ideal rates of growth in height and weight for the various ages.

To establish the normality of our laboratory children, then, we have the following proofs. These laboratory children represent a somewhat better proportion of weight to height than the private-school children, represent a relationship of height to age and weight to age not quite so good as the children in private schools, but better than many of the earlier standards, and consequently may legitimately be regarded as of a degree of normality to satisfy present-day criteria.

PULSE-RATE.

One of the most striking indices of apparent changes in metabolic activity, induced either by muscular activity or by febrile conditions, is the pulse-rate. In our earlier treatment of the physiology of normal infants,[1] we laid special emphasis upon the importance of knowing the fluctuations in the activity as exhibited by the kymograph record of the movements of the crib and particularly upon the relationships between this curve for activity and both the pulse-rate and the metabolism.

Before the study of new-born infants, our observations on children were so scattered and represented so few normal subjects that we were unable to record normal pulse-rates for children of various ages. With the new-born infants, however, this was perfectly feasible, and in the report of that study,[2] data were recorded giving the average pulse-rate for the first 8 days after birth as 112 on the first day, and for the 7 subsequent days 114, 116, 116, 116, 122, 119, and 126, respectively. These average values were obtained from a considerable number of counts for different children. Those for the first day after birth represented 50 new-born infants, but on the later days the number of subjects was less, particularly on the seventh and eighth days.

In our report of the observations on the few normal subjects, made in the first study of the gaseous metabolism of infants,[1] we were primarily interested in such alterations in the pulse-rate of an individual infant as were due to changes in activity and not in the alterations due to changes in age. Accordingly, in this earlier study the period of observation did not exceed 30 to 45 days, except with a single infant. In the accumulation of our new data, however, special stress was laid upon the trend of the pulse-rate as the age increased. This could be studied advantageously in those series of observations in which the metabolism of the same child was studied over periods of 4 months or more, and in a few cases 3½ years. Finally, with the older children, the unusually advantageous conditions under which the data were obtained make it seem desirable for us to record the pulse-rates and deduce therefrom average values which might be expected from children under quiet conditions.

Even the earliest observers noted that the pulse-rate of infants was very difficult to obtain and varied under different circumstances. The great difficulties in securing accurate records can perhaps be no better expressed than by quoting from the earliest report that we have found in English of observations on the pulse-rate of children. Publishing in 1694, Walter Harris of London stated:

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, table 19, p. 115.

> "But the Pulses of Children are naturally, or upon every little Alteration, do become so swift and frequent, that they always seem somewhat Feverish. Moreover, they are for the most part, so chagreen and froward, that not keeping their Wrest one moment in the same posture, do not suffer their Pulse to be touched. Lastly, there are so many things that do accelerate or otherways change their Pulses, that Sentiments taken thence should prove very uncertain, if not altogether false." [1]

In the interesting book of Benjamin Waterhouse[2] we find a quotation from a paper read in 1768 at the Royal College of Physicians in London by the venerable Dr. Heberden:

> "The pulse of children under two years old should be felt when they are asleep; for their pulses are greatly quickened by every new sensation, and the occasions of these are perpetually happening to them while they are awake. The pulse then of a healthy infant asleep on the day of its birth, is between 130 and 140 in one minute; and the mean rate for the first month is 120, for, during this time, the artery often beats as frequently as it does the first day, and I have never found it beat slower than 108. During the first year the limits may be fixed at 108 and 120. For the second year at 90 and 108. For the third year at 80 and 100. The same will very nearly serve for the fourth, fifth, and sixth years. In the seventh year the pulsations will be sometimes so few as 72, though generally more; and therefore, except only that they are more easily quickened by illness, or any other cause, they will differ but little from the healthy pulse of an adult, the range of which is from a little below 60 to a little above 80. It must be remembered, that the pulse becomes more frequent, by ten or twelve in a minute after a full meal."

No further evidence as to the difficulties of making these physiological records is necessary. Perhaps the best confirmation of this evidence is the fact that so little is now known regarding the quiet resting pulse of children. On looking over the literature on the normal pulse-rate of children, it is at once obvious that very little interest has been taken in the subject and few accurate counts have been made which take into consideration all the factors which modify the normal rate of the heart. It has been the custom of practically all writers to report minimum and maximum pulse-rates and to follow what seems to us the very confusing and entirely irrational procedure of averaging these and reporting the result as the average pulse-rate. A summation of our data shows that any pulse-rate above the minimum is profoundly affected by the degree of activity; therefore, little, if any, value can be placed upon observations of pulse-rate other than those obtained with the child in repose. It is of importance to know to what extent maximum pulse may develop during paroxysms of crying and with such activity as a child may exhibit when lying in bed, but for all normal purposes such records have but little, if any, scientific value.

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[1] Harris, An exact enquiry into, and cure of the acute diseases of infants. London, 1694, p. 9.

[2] Waterhouse, An essay concerning tussis convulsiva or whooping cough, with observations on the diseases of children. Boston, 1822.

The younger the infant the greater is the difficulty of obtaining the pulse-rate. With older children the element of apprehension should not be entirely disregarded. If this apprehension is not present to any great degree, the special precautions necessary for small children will not be required for the older individuals. Our measurements were all made while the child was inside a hermetically sealed chamber, and the routine was invariable for all children studied.

METHODS OF OBTAINING PULSE-RATE.

The pulse-rate can be obtained either by palpation at the wrist or by direct auscultation from the heart. During infancy it is difficult to obtain an accurate pulse-rate from the wrist, because infants rarely remain quiet for more than a few seconds. Infants dislike to be forced to stay in one position, and when made to do so they usually struggle and cry. It is often impossible to get the pulse-rate from the wrist while the infant is asleep, for the slightest touch of the observer's hand wakens the child. The difficulties present during the waking hours are then accentuated by the fright which may result from the sudden awakening. Obtaining the pulse-rate by means of a stethoscope held over the heart is also attended by many difficulties. Unless an infant is phlegmatic or becomes used to this procedure, he may squirm and cry and sometimes violently resist the application of the stethoscope. When a child or an infant resists, it is obviously impossible for the observer both to hold the stethoscope on the chest-wall and to make an accurate record of the pulse-rate unless someone holds the infant.

The most successful method of obtaining an accurate pulse-rate is by means of a small Bowles stethoscope fastened with adhesive plaster to the body-surface of the infant over the heart. A long rubber tube is run from the stethoscope under the clothing and out to the earpieces. The child can then take any position he desires without feeling that he is restricted and without realizing that the stethoscope has been applied. All of our own pulse-counts were obtained by this method.

In full recognition of the difficulties attending a study of the pulse-rate, we have tabulated the results of our observations, taking into consideration only the minimum pulse-rate. Our studies contribute towards the solution of two main physiological problems: First, how does the pulse-rate vary with age; secondly, what is the average pulse-rate for children of various ages? Since the number of observations made was considerable, the results offer a fair basis for answering these questions.

INFLUENCE OF AGE UPON THE PULSE-RATE.

The pulse-rate at the end of fetal life is said to average between 135 and 140 per minute, but it is only with extra-uterine pulse-rate that our observations deal. In the study of new-born infants we were able in no case to make observations of the pulse-rate of the same child throughout the entire first week. The average pulse-rates for the first seven or eight days of life given in the report of that study must consequently be looked upon as showing only the general trend of the average pulse-rates of new-born children.

In our first report we tabulated all of the available data for the pulse-rate for each of the first 8 days after birth, regardless of whether the measurement of the metabolism during these periods gave strictly minimum results or not.[1] Our conclusions were based upon these pulse data, but it was definitely stated that the values for the pulse-rate were those of infants during periods of approximately minimum heat production and that the metabolism during these periods could be considered as absolutely minimum in only a relatively few cases. In this publication it seems best to present the data for the pulse-rate of new-born infants for comparison purposes, using as a basis of selection, however, the periods in which the minimum heat production was obtained. The pulse-rates for these periods of minimum heat production are given in table 16. A comparison of the figures for pulse-rate given in the earlier report[2] with those in table 16 shows that this later method of selection lowered the daily averages on all but the first and fourth days, there being no change on these days; that is, when the effort is made to tabulate only pulse-rates with minimum heat production, in most cases this approximation to the minimum heat production is accompanied by a distinct reduction in the average pulse-rate. Since all of the subsequent material on pulse-rate in this report is based upon the values found during minimum muscular activity, for the final summation of pulse-rate values for children the averages given in table 16 will be used rather than those in the earlier report.

TABLE 16.—*Pulse-rate during first 8 days after birth.*

Age.	No. of subjects.	Average pulse-rate.
First day	50	112
Second day	25	110
Third day	19	109
Fourth day	20	116
Fifth day	14	113
Sixth day	7	118
Seventh day	4	114
Eighth day	1	95

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, table 19, p. 115.

[2] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, p. 116.

TABLE 17.—*Basal pulse-rate of boys at different ages.*

No. of subject.	1 mo.	1½ mo.	2 mo.	2½ mo.	3 mo.	4 mo.	5 mo.	6 mo.	7 mo.	8 mo.	9 mo.	10 mo.	11 mo.
61	.....	.....	136	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
115	118	124	130	130	.....	138	130	128	112	121	.....	.....	.....
117	.....	94	120	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
118	.....	126	117	109	127	122	.....	.....	.....	.....	.....	.....	.....
119	.....	123	.....	.....	.....	121	104	119	122	121	.....	.....	.....
124	.....	.....	120	115	.....	.....	.....	.....	.....	.....	.....	.....	.....
125	.....	.....	125	120	111	.....	.....	.....	.....	.....	.....	.....	.....
126	.....	.....	.....	111	110	.....	.....	113	107	.....	.....	.....	.....
128	.....	.....	.....	.....	116	.....	.....	.....	.....	.....	.....	.....	.....
129	.....	.....	.....	.....	109	.....	.....	.....	.....	.....	.....	.....	.....
130	.....	.....	.....	.....	113	.....	.....	.....	.....	.....	.....	.....	.....
132	.....	118	.....	.....	123	118	.....	.....	.....	.....	.....	.....	.....
133	.....	.....	.....	.....	.....	134	.....	.....	.....	.....	.....	.....	.....
136	.....	.....	.....	.....	.....	114	119	129	116	.....	119	114	.....
137	.....	.....	.....	.....	.....	115	.....	.....	.....	.....	.....	.....	.....
138	.....	.....	.....	.....	.....	132	133	129	.....	.....	.....	.....	116
141	.....	.....	.....	.....	.....	.....	124	.....	.....	.....	.....	.....	.....
142	.....	.....	.....	.....	.....	122	115	103	.....	117	104	116	.....
147	.....	.....	.....	.....	.....	.....	119	107	.....	.....	.....	.....	.....
148	.....	.....	.....	.....	.....	.....	108	117	112	112	.....	111	.....
149	.....	.....	.....	.....	.....	.....	.....	101	.....	.....	.....	.....	.....
150	.....	.....	.....	.....	.....	.....	.....	109	.....	.....	.....	.....	.....
153	.....	.....	.....	.....	.....	.....	.....	110	110	111	113	113	.....
154	.....	.....	.....	.....	.....	.....	.....	.....	127	.....	.....	.....	.....
155	.....	.....	.....	.....	.....	.....	.....	.....	115	112	115	117	.....
156	.....	.....	.....	.....	.....	.....	.....	.....	126	.....	.....	.....	.....
157	.....	.....	.....	.....	.....	.....	.....	.....	120	.....	.....	.....	.....
158	.....	.....	.....	.....	.....	.....	.....	.....	123	115	95	.....	.....
159	.....	.....	.....	.....	.....	.....	.....	.....	119	.....	.....	.....	.....
161	.....	.....	.....	.....	.....	.....	.....	.....	.....	123	145	.....	.....
164	.....	.....	.....	.....	.....	.....	.....	.....	118	.....	108	.....	.....
168	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	109	.....
170	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	109	.....

No. of subject.	12 mo.	14 mo.	16 mo.	18 mo.	20 mo.	22 mo.	24 mo.	26 mo.	28 mo.	30 mo.	32 mo.	34 mo.	36 mo.	38 mo.
119	.....	125	110	108	92	.....	94	.....	.....	.....	.....	.....	.....	.....
138	.....	.....	111	106	127	104	96	.....	.....	.....	.....	.....	.....	.....
148	112	.....	.....	106	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
153	118	.....	.....	103	107	107	101	.....	100	110	.....	93	98	.....
155	.....	.....	.....	.....	.....	.....	.....	.....	.....	107	.....	96	.....	.....
158	135	123	.....	112	116	107	84	87	.....	93	86	83	83	75
161	.....	126	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
175	.....	.....	.....	.....	.....	.....	.....	.....	.....	94	.....	.....	.....	.....
176	.....	.....	.....	.....	.....	.....	.....	.....	.....	85	.....	.....	.....	.....

For the first 5 days after birth the number of infants is sufficiently large to justify a study of the general trend of the pulse-rate during this time. On the last 3 days the number is obviously too few, but the results are included here to complete the data. From this table it can be seen that there is a slight tendency for the pulse-rate to rise and remain at the higher level after the first 3 days, with a tendency to decrease successively on the first 3 days. All of these values are measurably less than that reported for the last hours of fetal life.

TABLE 18.—*Basal pulse-rate of girls at different ages.*

No. of subject.	9th day.	11th day.	12th day.	2 wks.	3 wks.	1 mo.	1½ mo.	2 mo.	2½ mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	94	97	95	112									
35						134					125		
48						127	159			139			
49		115			126								
110		118		125									
113					146	134	132	134	120	134	120	116	121
116							123	132					
120								123					
122								125		138	135		
123								130	125	122			121
127										117			
131										121	127	121	127
134											106		
135											103	110	
139												131	126
140												113	118
144												121	
145												117	
146												121	132
151													126
152													121

No. of subject.	7 mo.	8 mo.	9 mo.	10 mo.	11 mo.	12 mo.	14 mo.	16 mo.	18 mo.	20 mo.	22 mo.	24 mo.
122								138	132			
123	113		115									
127				125	115	113	114	109	100			
131	120	122										
139	128		128	123			133	117	122	110	103	
145				117	110	108	109	98	103		88	83
146	122											
160	123	126		125		115	116					
162		119										
163		116										
165			101									
166			111		128	126	117	105		100	106	88
167			127									
171				132		165	136	119	123		116	114
172						123	124	118	119	106		
173						121	120	111	103			
174												104

No. of subject.	26 mo.	28 mo.	30 mo.	32 mo.	34 mo.	36 mo.	38 mo.	40 mo.	42 mo.	44 mo.	46 mo.	4 yr.
139	110		100	93			91	80		82	85	
145	73	70			76	74	71	70				
166	98	86			96	90	90	76				
171		111	101					91				90
178					88							
180											91	
181											88	
183												78
184												93

In the present report we are more particularly interested in the pulse-rates of children over a week old. To eliminate completely the possibilities of sexual differentiation, a subject which will be discussed somewhat later in this report, we have tabulated the values for boys and girls separately, those for boys appearing in table 17 and those for girls in table 18. Unlike the average pulse-rates for new-born infants shown in table 16, the pulse data presented in tables 17 and 18 do not represent the pulse-rates obtained in the periods of minimum heat production. The basis of selection here used was the degree of muscular repose, the pulse-rates tabulated being those obtained in periods of minimum activity, as indicated by the tracings on the kymograph, without reference to the heat production. The pulse-rates of boys and girls as presented in these tables offer an opportunity for studying the basal pulse-rate of the same child at varying ages. This is particularly true of boys up to the age of 38 months and of girls up to 4 years.

One of the longest series for boys is that with No. 119. The irregularities in the figures reported for this subject show clearly that there is very little evidence of a definitely established trend until the child is somewhat over a year old, but that during the second year there is a distinct tendency for the pulse-rate to decrease. Another long series is represented by No. 158. Here again considerable irregularity is noted previous to the age of 14 months; thereafter there is a reasonably uniform decrease. These irregularities during the first 14 months are to be observed with practically all of the boys. During the second year of life, however, the values indicate a definite tendency toward a generally lowering pulse-rate.

This finding with boys is likewise noticeable with girls, although the irregularity in the first year is by no means so striking. Indeed, with a number of subjects there is a reasonable degree of decrease in the pulse-rate subsequent to the age of 4 or 5 months. It is characteristic of all these children, however, that after the first year and a half the decrease is reasonably well established.

AVERAGE PULSE-RATE OF CHILDREN.

The second important factor to which our data contribute is the average pulse-rate of children of the same age, both as to its absolute value and as to the deviation therefrom which can be expected for children in repose. With boys, one of the most extensive series numerically that we have for any age represented in table 17 is that for the group 7 months old, in which the basal pulse-rate for the 13 boys ranged from 107 (No. 126) to 127 (No. 154). The average for this group is found to be 117. It is clear, therefore, that it is only with a great deal of reserve that one may speak of the pulse-rate of a boy of 7 months as being 117. Even wider differences are observed with the 4 boys of 20 months, the lowest being 92 and the highest 127, with an average of 111.

From the foregoing discussion of the considerable variation to be found with an individual in the earlier years, one would naturally expect similar large differences between groups of older children of the same age. The considerable amount of data obtained for the first four years of a child's life have been supplemented by records for older children, which are given in table 19 for boys and girls 5 to 13 years of age. Almost without exception, however, the averages in this table represent individual children, the data for each child, except in one case, being obtained at only one age. Here again we find considerable differences. Thus, for the 7 boys 7 years of age, the lowest is 74 and the highest 99. With the 5 boys 9 years of age, the lowest record is 71 and the highest 86, while the 9 boys 11 years of age show a maximum difference in their basal pulse-rates of 22 beats.

TABLE 19.—*Basal pulse-rate of individual children 5 to 13 years of age.*

Boys.								Girls.					
6 yrs.	7 yrs.	8 yrs.	9 yrs.	10 yrs.	11 yrs.	12 yrs.	13 yrs.	5 yrs.	7 yrs.	8 yrs.	9 yrs.	10 yrs.	12 yrs.
90	99	79	84	80	89	67	74	114	76	76	83	84	74
72	74	79	71	81	82	68	68	79	74	86	97	85	76
86	84	69	73	89	76	67	71	82	71	69	83	69	78
.....	83	94	86	.....	69	66	80	90	.....	.....	85	80	.....
.....	85	.....	78	.....	76	65	.....	.....	.....	.....	88	.....	.....
.....	81	.....	.....	.....	78	79	.....	.....	.....	.....	71	.....	.....
.....	77	.....	.....	.....	72	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	67	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	69	.....	.....	.....	.....	.....	.....	.....	.....

With girls, one of the largest groups at the earlier ages is that for 6 months, but the pulse-rates for these 8 girls range only from 118 to 132, with an average of 124. This approach to uniformity, which is much closer than that noted for boys, does not by any means hold for all ages, since at 16 and 18 months differences amounting to 40 and 32 beats, respectively, are observed. The largest group for the older ages represented in table 19, that for 9 years, has values for pulse-rate for the 6 girls ranging from 71 to 97. The extraordinarily high value of 114 for one of the 5-year-old girls may have some special explanation which is at present unknown to us.

Bearing in mind the irregularities seen in the careful examination of the data for these several age-groups, we may average these pulse data and attempt to portray the general trend of the minimum or basal pulse-rate of boys and girls from birth to 13 years of age. In so doing we have left out of the averaging all age-ranges represented by less than three individuals. These values are brought together in table 20.

The average values shown for boys indicate a reasonably constant pulse-rate for the first 14 months of life, ranging from 113 to 125, if

TABLE 20.—*Comparison of average minimum pulse-rates of boys and girls.*

Age.	Boys.		Girls.		Age.	Boys.		Girls.	
	No. of subjects.	Average minimum pulse-rate.	No. of subjects.	Average minimum pulse-rate.		No. of subjects.	Average minimum pulse-rate.	No. of subjects.	Average minimum pulse-rate.
1 day ..	29	*113*	21	110	16 mos...	....	....	8	114
2 days..	13	108	12	*112*	18 mos...	5	107	7	*115*
3 days..	8	105	11	*112*	20 mos...	4	*111*	3	105
4 days..	11	*117*	9	114	22 mos...	3	*106*	4	103
5 days..	11	*114*	3	111	24 mos...	4	94	4	*97*
6 days..	....	....	5	118	26 mos...	....	....	3	94
11 days..	....	....	3	110	28 mos...	....	....	3	89
1 mo. ..	....	....	3	132	30 mos...	5	98	....	....
1½ mos..	5	117	3	*138*	34 mos...	3	*91*	3	87
2 mos...	6	125	5	*129*	38 mos...	....	....	3	84
2½ mos..	5	117	....	....	40 mos...	....	....	4	79
3 mos...	7	116	6	*129*	46 mos...	....	....	3	88
4 mos...	9	*124*	6	119	4 yrs. ..	....	....	3	87
5 mos...	8	119	8	119	5 yrs. ..	....	....	4	91
6 mos...	11	115	8	*124*	6 yrs. ..	3	83	....	....
7 mos...	13	117	5	*121*	7 yrs. ..	7	*83*	3	74
8 mos...	8	117	4	*121*	8 yrs. ..	4	*80*	3	77
9 mos...	7	114	5	*116*	9 yrs. ..	5	78	6	*85*
10 mos...	7	113	5	*124*	10 yrs. ..	3	*83*	4	80
11 mos...	....	....	3	118	11 yrs. ..	9	75	....	....
12 mos...	3	122	7	*124*	12 yrs. ..	6	69	3	*76*
14 mos...	3	*125*	8	121	13 yrs. ..	4	73	....	....

we exclude the first 5 days, and from 105 to 125 if these earlier values are included. Thereafter the picture is a gradual decrease, persisting throughout the second and much of the third year. The data between 3 and 6 years are lacking. During this period there has been a very considerable fall, the tendency to a decrease continuing subsequent to 7 years. The lowest value is 69 at the age of 12 years. With girls, the averages show that after the first 11 days there is a distinct tendency for a rise in pulse-rate, the return to the rate of the first week not taking place until shortly after the end of the first year. There is then a continued decrease, the lowest record being 74 at the age of 7 years.

SEX AND MINIMUM PULSE-RATE.

The intimate relation between pulse-rate and metabolism, shown with the same individual in the large majority of observations in this laboratory, makes a careful examination of pulse-rate with respect to sex of special importance. The analysis of data for the basal metabolism of men and women has shown that women as a class have a lower metabolism than men, not only per individual, but per unit of weight. On the other hand, the pulse-rate of women as a class was shown to be higher than that of men, as measurements for 90 women and 121 men in our series gave an average of 68.67 for women and

61.26 for men.[1] These differences are substantiated by the fact that with men three different groups of 28, 116, and 50 men showed average pulse-rates of 62.5, 61.3, and 61.3, respectively. Two groups of women, one of 68 and the other of 22, showed pulse-rates of 69.1 and 67.3, respectively. In other words, it seems thoroughly established that the women as a class have a pulse-rate somewhat higher than men, in spite of the fact that their metabolism is distinctly lower. This supplies very clear evidence that while pulse-rate and heat production may be closely correlated in the same individual, in groups of individuals the pulse-rate may vary enormously and "average" pulse-rate may have little, if any, connection with "average" heat production.

Since the pulse-rates of men and women show a difference, it becomes extremely important, in studying our groups of children, to note at what point, if any, there is a definite change in the pulse-rate, and further comparisons of values for males and females will be of special interest in this connection. Such comparison may be made from the pulse-rate data for boys and girls in table 20, which gives an opportunity of noting the differentiation, if any, due to sex. To this end, wherever values for both boys and girls are recorded at the same age, the higher of the two values has been italicized. Thus, for children 1 day old, 29 boys gave an average minimum pulse-rate of 113, while 21 girls had a pulse-rate of 110. On the next day the conditions for very nearly the same number of boys as girls were reversed, the girls showing a pulse-rate 4 beats higher than the boys.

Pursuing this method of analysis for the entire group of data in table 20, and passing over those ages for which records are available for only one of the two sexes, we find that at 11 age-periods the boys have a higher pulse-rate than the girls of the same age, while at 15 age-periods the girls have a higher pulse-rate than boys of like age. On this basis, therefore, it would appear that the pulse-rate of the girls was, on the whole, somewhat higher than that of boys. The italicized figures in the table show no great regularity in the appearance of these high values with either sex. The most consistent record is that from 1½ months to 10 months, the only ages at which the girls are not higher being that of 4 months, and again of 5 months, when the average pulse-rate for both sexes is the same. After 10 months the italicized figures indicate but little regularity as to sex.

On the whole, the picture can not be said to speak pronouncedly for a higher pulse-rate with girls than with boys. In making this general conclusion, however, it is important to note that the data under consideration are at best somewhat meager, although they may be relied upon as far as they go. But many observations of the minimum resting pulse-rate of boys and girls are necessary before final conclusions can be drawn, for obviously the pulse-rate at other ages should be studied and supplementary data should be obtained for the higher ages included in our observations.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 66.

AVERAGE PULSE-RATE WITH INCREASING AGE.

From the foregoing analysis it can be seen that there is no striking difference between the pulse-rates of girls and boys. Accordingly, as a tentative measure of the average minimum resting pulse-rate of children of both sexes, we have taken the values given in table 21 as approximately normal values. In view of the special conditions under which these pulse-rates were obtained, namely, complete muscular repose and with the subject entirely unconscious of the records, it is seen that we have here true physiological values uncontaminated by activity.

TABLE 21.—*Approximate normal minimum values for pulse-rates of children during complete muscular repose.*

End of year.	Av. min. pulse-rate.	End of year.	Av. min. pulse-rate.
First	122	Seventh	78
Second	100	Eighth	78
Third	89	Ninth	82
Fourth	87	Tenth	81
Fifth	91	Twelfth	72

RECTAL TEMPERATURE.

Any physiological study of body temperature, to be of true scientific value, must deal with temperatures taken deep in the body trunk. The extraneous factors of exercise, mouth-breathing, and the effect of previously taken foods so greatly vitiate all measurements of the buccal temperature that they have little, if any, value except for demonstrating the absence of fever. It has been the custom of many clinicians to take the temperature of young children in the axilla or in the groin. These records, aside from likewise showing the presence or absence of fever, have no physiological value, for it has been found that even when these cavities are well-closed a very considerable period of time is required to raise their temperature to that approximating the interior of the body.

In our study of certain physiological factors during growth, the rectal temperature was measured primarily to demonstrate the absence of any febrile condition, since the presence of fever would of course preclude further observations with the child in this abnormal state. Every reasonable effort was made to have these measurements meet the exactions of scientific accuracy, but as ordinary clinical mercury thermometers were used, even though well-tested, and there were changes in the personnel of the assistants from time to time, as well as possibilities of difference in the depth of insertion of the thermometer bulb, we may not look upon these observations as a refined physiological study of changes in body temperature of children.

It is to be regretted that a study of the diurnal rhythm of the rectal temperature of children of various ages could not have been included in the research, but this was impracticable. To use occasional observations of rectal temperature as a basis for determining the physiological temperature of children is open to serious question, since the well-known influences of activity, ingestion of food, and sleep make such measurements liable to gross variability. When one considers that the normal range in temperature is but 2° or 3° F., it will be seen that if a study of the body temperature is to be made with strict scientific accuracy, a much more sensitive measurement should be used than that employed in this research. But as the measurements were all made with the child inside a chamber, lying quietly on a comfortable bed, we believe that although the method was admittedly defective, the conditions were essentially comparable and the values may legitimately be used for drawing conclusions.

The rectal temperature was usually recorded, at least with the younger children, just before and just after each respiration experiment. Several hundred observations of the body temperature of these children were thus obtained. It appeared unnecessary to give detailed publication of all these records, and we have therefore averaged the two observations for each experiment and grouped them in table 22, according to sex, as general averages for certain average ages. In these averages the relatively few records of 100.5° F. or over have not been included. The number of observations entering into each average is also shown in the table. If measurements were made with but a single subject for any particular age, the values were not included in this comparison. From these average values an indication of the general trend of the body temperature of children during the period of growth may be obtained.

The values for boys range from 97.1° F., the very low value for the two boys averaging 5 years of age, to a maximum of 99.5° F. in the group of six boys for 1½ years. During the first month or two of life the temperatures for boys are somewhat low, but with evidence of a tendency to rise thereafter, the maximum continuing for approximately two or three years. Subsequently the figures incline to run below rather than above 99° F., and after 10 years all values are 98.8° F. or under. Special attention has already been called to the extraordinarily low value of 97.1° F. for the two boys 5 years of age, which must not be looked upon as characteristic of that age.

This table must not be considered as indicating the minimum temperatures at these various ages. According to previous experimenting

TABLE 22.—*Average rectal temperature of boys and girls at different ages.*

Boys.				Girls.			
No. of subjects.	No. of measurements.	Average age.	Average rectal temperature.[1]	No. of subjects.	No. of measurements.	Average age.	Average rectal temperature.[1]
			°F.				°F.
44	88	¾ hr. to 24 hrs.	[2]98.2	30	60	¾ hr. to 24 hrs.	[2]98.3
34	68	1 to 2 days	[2]98.7	31	62	1 to 2 days	[2]98.8
31	62	2 to 3 days	[2]98.8	29	58	2 to 3 days	[2]99.0
27	54	3 to 4 days	[2]98.5	24	48	3 to 4 days	[2]98.7
22	43	4 to 5 days	[2]98.5	18	36	4 to 5 days	[2]98.5
9	17	5 to 6 days	[2]98.7	13	26	5 to 6 days	[2]98.5
10	20	6 to 7 days	[2]98.5	6	12	6 to 7 days	[2]98.6
6	12	7 to 8 days	[2]98.8	3	6	7 to 8 days	[2]98.7
7	22	8 to 20 days	98.7	8	30	8 days to 3 wks.	98.5
6	19	1 mo.	98.7	4	16	1 mo.	98.9
8	50	2 mos.	99.0	6	22	2 mos.	99.1
8	30	3 mos.	99.1	7	27	3 mos.	98.9
8	36	4 mos.	99.0	7	38	4 mos.	98.8
8	30	5 mos.	99.1	9	32	5 mos.	98.9
11	40	6 mos.	99.0	8	35	6 mos.	98.9
13	47	7 mos.	99.0	6	24	7 mos.	98.9
6	20	8 mos.	99.0	4	10	8 mos.	98.9
8	32	9 mos.	98.8	8	26	9 mos.	99.3
4	18	10 mos.	99.1	5	14	10 mos.	99.1
5	18	1 yr.	99.3	5	16	11 mos.	99.5
6	58	1½ yrs.	99.5	8	89	1 yr.	99.4
5	23	2 yrs.	99.3	8	74	1½ yrs.	99.5
6	26	2½ yrs.	99.0	6	46	2 yrs.	99.4
3	16	3 yrs.	99.1	4	30	2½ yrs.	99.3
2	2	5 yrs.	97.1	5	30	3 yrs.	99.2
2	4	5½ yrs.	98.4	5	19	3½ yrs.	99.2
7	21	7 yrs.	99.1	4	13	4 yrs.	98.9
5	15	8 yrs.	98.6	4	7	4½ yrs.	98.4
3	7	8½ yrs.	99.2	3	4	5½ yrs.	98.1
2	4	9 yrs.	99.1	2	4	6½ yrs.	98.5
3	6	9½ yrs.	99.1	3	6	8 yrs.	98.8
2	6	10½ yrs.	98.6	5	15	9 yrs.	98.4
2	10	11 yrs.	98.6	2	4	9½ yrs.	98.8
3	10	11½ yrs.	98.3	2	5	10½ yrs.	98.8
2	6	12½ yrs.	98.7	2	5	11 yrs.	98.8
				3	7	12 yrs.	98.6

[1] Any reading of 100.5° F. or over was excluded from these averages.
[2] Data obtained from table 9, Carnegie Inst. Wash. Pub. No. 233, 1915, pp. 46–79.

in this laboratory, the minimum temperature was found some time during the early morning hours, when the subjects were in deep sleep and the stomachs practically empty. As an indication of the influence of age, however, we believe that these values are not without significance. It is important to call attention here to the fact that the period of highest average rectal temperature, as shown by these more or less heterogeneous data for boys, is not far from 10 months to 2 years. As will be seen later, this corresponds to the period of relatively highest metabolism. While the evidence is by no means beyond criticism, it is of significance at least to point out this coincidence between the maximum metabolism and the high average rectal temperature.

The values obtained with girls are somewhat better distributed for the different ages than those with the boys. These range from a minimum of 98.3° F. for girls on the first day of life, to a maximum of 99.5° F. at 11 months and 1½ years of age. Here again we find a relatively low temperature in the first few weeks of life with a subsequent rise and a high period from 11 months to 2 years of age. Thereafter the temperatures with girls begin to fall and subsequent to 3½ years are below 99° F. In this respect, therefore, the picture exhibited by the average temperature values for girls confirms in a striking manner that noted for boys. Here, also, the maximum level in the body temperature, *i. e.*, from 11 months to 2 years, corresponds to the maximum level for the metabolism, which will be subsequently noted. No pronounced sex differentiation in the values for boys and girls is apparent from these two groups of data.

While it seemed inadvisable to publish the individual records of the body temperature, the data have been carefully compared to note the differences, if any, between the records at the beginning and end of the experiment. The influence of muscular activity and, in some cases, that of food obtain in these measurements. For the experiments the child was placed in the chamber and instructed to remain quiet. No observations were made until this quiet condition had been secured. During the experiment of an hour or more, and with conditions of reasonably complete muscular repose and frequently sleep, there would normally be a definite fall in temperature. On the other hand, the experiments were at times continued until the child awoke or became restless; this activity would make it necessary to discontinue the experiment, since the main object was a study of the basal metabolism. Under these conditions, the activity at the end of the experiment would tend to increase the body temperature and the second record would thus be higher.

A study of all the experiments in which records were obtained at the beginning and end shows that in the 189 experiments with boys used in the minimum-metabolism table (see table 27, page 116), there was no rise or fall in 19 experiments, an average rise of 0.55° F. in 52 cases, and an average fall of 0.71° F. in 118 cases. Thus, with the boys, 10 per cent of these 189 experiments showed no change in body temperature, 27.5 per cent showed a rise, and 62.5 per cent a fall, the range in variation being from +0.55° F. to −0.71° F. In the 214 experiments with girls used in the minimum-metabolism table (see table 28, page 120), there was no change in temperature in 24 experiments, an average rise of 0.49° F. in 51 experiments, and an average fall of 0.71° F. in 139 experiments. In these experiments with girls, therefore, there was no change in 11.2 per cent, a rise in 23.8 per cent, and a fall in 65 per cent, with a range in average variation from +0.49° F. to −0.71° F.

While in this comparison only those experiments were used which were included in the minimum metabolism tables, but little if any difference in the results was found when all the measurements were compared. It may be safely concluded, therefore, that there was a tendency in general for the temperature to fall during the experiments and that this was independent of sex. The body temperatures were usually below 100° F. and, if 100° F. at the beginning, generally fell below at the end. This tendency to a fall was undoubtedly due to the contrast between the quiet and muscular relaxation in the experimental period and the pre-experimental activity. This interpretation of the change is made the more probable by the fact that, from an inspection of the records showing a rise at the end of the experiment, it appears that in the majority of cases the increase in body temperature was accompanied by a considerable degree of activity in the last period of the experiment.

In the majority of experiments with children older than 2 years, the temperature measurement was made only at the end of the experiment. Accordingly, this comparison of the measurements before and after the experiment applies more particularly to children 2 years old or younger, although some 20 boys and 5 girls are included in the data compared who were over 2 years of age. In conclusion, it may be said that these observations on the body temperature of young children indicate, on the whole, that during the first two years of life there is a definite tendency for the rectal temperature to increase slightly, with a maximum at about 2 years of age. Thereafter the body temperature slowly falls, with no perceptible general trend apparent from 5 to 13 years of age. These variations in temperature show strikingly the desirability of more extensive studies of the diurnal range by means of some more sensitive measurement, such as a bolometric or thermoelectric method, with continuous or semi-continuous registration.

INFLUENCE OF FOOD ON METABOLISM.

As outlined in a previous section (see page 30), with the youngest children it was not possible to obtain ideal conditions for measuring the basal metabolism, *i. e.*, complete muscular repose and with no food in the alimentary tract, or the "post-absorptive" condition. With adults the post-absorptive condition is usually not secured until 12 hours after an ordinary meal and the maximum increase following a protein-rich meal may be as high as 40 to 50 per cent for a short time, with its effect possibly continued even longer than 12 hours. With the children observed in this study, excessively large meals were not the rule, the last meal before the observations with the respiration apparatus being purposely considerably reduced.

A careful control of the muscular activity was secured through graphic records. With the youngest children, and especially the infants, however, it was not possible to obtain the required degree of muscular repose when there was no food in the stomach, because the want of food caused restlessness and frequently crying. In recognition of this difficulty, it was necessary to compromise by supplying as small an amount of food as would produce comfort and consequent muscular repose. This amount of food, even though small, inevitably influenced the metabolism. When older children were studied, it was possible to postpone the observations after a meal for a longer period of time, even for 4 or 5 hours. Accordingly, in the subsequent analysis of the metabolism data for the children of various ages, it must be remembered that as the age of the children increases the influence of the ingestion of food decreases correspondingly. The basal metabolism of children under 2 years of age can thus be compared with that of older children only on the distinct understanding that the values for the basal metabolism for the younger children are higher than they normally would be, owing to the influence of food.

The quantitative measurement of the influence of the ingestion of food upon the metabolism of infants should be given special study, such as has been done for adults in a previous publication from this laboratory.[1] Certain more or less fragmentary evidence has, however, been accumulated in the present research with children, in part by design and in part by accident. With several of the children, a prolonged series of observations was made after food had been taken, some of these continuing 9 or 10 hours without interruption. The results of these observations give some information as to the possible influence of food. Here again we find a difficulty in interpretation in that the somewhat subtle influence of food is profoundly affected by a change in the activity; hence only periods of comparable muscular activity, or preferably muscular repose, can legitimately be used to determine the influence of food upon the metabolism. That is, it must be assured that the increase in the metabolism after food is not due to muscular activity before assuming it is due to the stimulus of food.

The data contributing to a study of this problem are brought together in table 23, in the order of increasing age. Unfortunately, long observations during which the minimum metabolism after feeding has been measured were made only with relatively young children, the oldest being but 13½ months old. This table gives not only the age and weight of the individual children, but also the energy content of the food, the time of feeding, the interval between the food and the end of the period of observation, the heat produced on the basis of 24 hours, the pulse-rate, and the relative activity. The time when presumably basal metabolism was reached is indicated by an italicization of the lowest value for heat.

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[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918.

TABLE 23.—*Heat production of infants after food.*

Subject No., age, and weight.	Date.	Energy of food.	Time of feeding.	Interval between food and end of period.	Heat produced per 24 hours.[1]	Pulse-rate.	Relative activity.[2]
	1916	*cals.*		*h. m.*	*cals.*		
127 (2½ mos.; 5.03 kilos)....	Apr. 20–21	60	$6^h48^m$to 7^h07^mp.m.	1 21	287	117	I
				1 56	301	119	II
				2 32	286	118	I
				3 7	287	116	I
				3 44	299	112	III(?)
				4 20	281	114	II
				4 57	*255*	115	III(?)
				5 31	267	115	II
	Apr. 21	90	1 12 to 1 21 a.m.	1 11	291	121	II
		90	6 42 to 6 50 a.m.	1 41	336	117	III(?)
		100	9 28 to 9 42 a.m.	1 18	280	115	II(?)
		60	12 32 to 12 47 p.m.	40	322	119	III(?)
115 (4½ mos.; 5.86 kilos)....	Mar. 25	80	5 40 to 5 48 p.m.	1 28	348	137	II
				2 10	335	131	I
				2 49	328	125	II
				3 32	312	125	I
	Mar. 25–26	110	9 54 to 10 35 p.m.	1 9	362	137	I
				1 44	312	128	I
				2 27	342	126	II
				3 11	*296*	124	II
119 (6 mos.; 7.21 kilos).....	Apr. 15–16	80	7 08 to 7 14 p.m.	1 8	403	107	I
				1 58	397	115	I
				2 39	397	118	I
				3 27	391	115	III(?)
				4 41	392	117	III
				5 18	373	122	II
				5 41	*369*	122	III(?)
	Apr. 16	210	2 06 to 2 26 a.m.	1 23	422	119	I
				1 50	477	129	II
				2 35	457	132	II(?)
				3 2	437	125	I(?)
140 (6 mos.; 6.38 kilos).....	Apr. 16–17	70	6 24 to 6 38 p.m.	1 24	380	113	I
				1 56	356	112	I
				2 30	405	114	I
				2 58	390	114	II
				5 3	356	109	II
				5 48	353	115	III
				6 13	*337*	109	II(?)
	Apr. 17	170	1 38 to 1 58 a.m.	1 0	364	119	II
				1 31	400	120	II
				2 7	359	112	II
				3 10	373	108	II
123 (6½ mos.; 6.09 kilos)....	Apr. 17–18	60	6 45 to 7 04 p.m.	1 11	334	118	I(?)
				1 42	359	124	I
				2 9	378	124	II
				2 35	361	125	I
				3 7	363	123	II
				3 39	349	121	I
				4 5	353	123	II

The lowest value, presumably the basal value, is italicized in each series of observations

The designations for the activity are given the following values: I, very quiet, probably asleep; II, slight movements, few in number; III, some activity, but generally quiet. The method of estimating the activity is described by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 136.

TABLE 23.—*Heat production of infants after food*—Continued.

Subject No., age and weight.	Date.	Energy of food.	Time of feeding.	Interval between food and end of period.	Heat produced per 24 hours.[1]	Pulse-rate.	Relative activity.[2]
	1916	*cals.*		*h. m.*	*cals.*		
123 (6½ mos.; 6.09 kilos)..... (Continued.)	Apr. 17–18	60	6h45m to 7h04m p.m.	4 35	330	118	I
				5 13	335	116	II
				6 9	333	119	II
				7 12	328	118	III
				8 1	322	120	I
				9 8	*312*	124	II(?)
131 (6½ mos.; 5.76 kilos)....	Apr. 19–20	50	6 46 to 6 51 p.m.	1 8	331	120	I
				1 43	354	129	I
				2 13	354	121	I
				2 45	371	130	II
				2 53	329	127	I
				3 46	340	128	II(?)
				4 16	315	129	II
				4 47	318	130	I
				5 59	342	130	I
				7 8	328	126	I
				9 7	326	141	I(?)
				9 36	391	143	I
	Apr. 20	100	5 56 to 6 02 a.m.	59	373	137	II
				1 48	392	131	II
				2 17	372	118	I
		90	8 59 to 9 07 a.m.	1 27	*299*	120	II
				2 25	328	119	I
				3 21	337	118	I
		100	3 51 to 3 57 p.m.	1 59	325	114	I
				3 6	323	122	II
139 (6½ mos.; 6.11 kilos)....	Feb. 19	130	5 35 to 5 44 p.m.	1 59	350	122	II
				2 50	363	123	I
				3 42	328	125	I
	Feb. 19–20	80	9 35 to 9 55 p.m.	1 13	393	129	II(?)
				2 4	371	129	I
				2 52	354	126	II
				3 41	342	125	I
				4 30	366	125	II
				5 50	332	127	III
				6 22	*325*	124	I
				7 19	345	125	II(?)
136 (7½ mos.; 9.08 kilos)....	Mar. 11–12	50	5 48 to 6 08 p.m.	1 31	500	106	II
				2 16	505	109	II
				3 10	471	106	II
				4 4	463	104	II(?)
				4 57	*461*	103	II(?)
				5 51	472	106	III(?)
				6 30	481	106	II
	Mar. 12	230	12 45 to 1 07 a.m.	1 15	501	109	I
				1 51	520	110	III
148 (8½ mos.; 8.87 kilos)....	Feb. 26	170	4 55 to 5 10 p.m.	2 28	493	108	I
				3 13	475	107	I
				3 58	481	106	II

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[1] The lowest value, presumably the basal value, is italicised in each series of observations.

[2] The designations for the activity are given the following values: I, very quiet, probably asleep; II, slight movements, few in number; III, some activity, but generally quiet. The method of estimating the activity is described by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 136.

TABLE 23.—*Heat production of infants after food*—Continued.

Subject No., age, and weight.	Date.	Energy of food.	Time of feeding.	Interval between food and end of period.	Heat produced per 24 hours.[1]	Pulse-rate.	Relative activity.[2]
	1916	*cals.*		*h. m.*	*cals.*		
184 (8½ mos.; 887 kilos)	Feb. 26	170	4^h55^m to 5^h10^m p.m.	4 47	*467*	108	II
				6 13	470	114	III
	Feb. 26–27	130	11 30 to 11 42 p.m.	1 24	511	117	I
				2 14	506	118	I
				2 52	516	113	II
				3 34	478	114	I
				4 5	522	112	II
				4 46	479	115	II
				5 21	502	117	I
171 (13½ mos.; 8.70 kilos)...	Mar. 4–5	310 170	4 00 to 4 10 p.m. 5 45 to 6 00 p.m.	2 27	629	136	II
				2 57	608	134	I
				3 29	647	133	II
				4 13	616	132	II(?)
				4 53	602	131	II
				5 44	584	128	III
				6 45	608	130	II(?)
				8 37	579	132	I
				9 11	*545*	129	II
				10 4	570	126	I
				10 51	554	129	I
				11 17	555	131	II

[1] The lowest value, presumably the basal value, is italicized in each series of observations.

[2] The designations for the activity are given the following values: I, very quiet, probably asleep; II, slight movements, few in number; III, some activity, but generally quiet. The method of estimating the activity is described by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 136.

The basal metabolism of a child, like that of an adult, is not necessarily a fixed factor; hence it is unjustifiable to use a basal value obtained on one day for comparison with the metabolism after food on another day to determine the effect of the food. The question of the selection of a suitable basal value for experiments in such studies has already been exhaustively discussed in a previous publication.[1] It was there pointed out that only basal values obtained on the same day were legitimate for comparison with the metabolism after food, and also that the metabolism after one or two days of fast was not a true basal value; also that for ideal comparisons the basal value without food should first be obtained and the metabolism with the superimposed factor of food studied immediately thereafter.

The most extensive series of observations after food were made with the three children Nos. 123, 131, and 171. Of these, the series with the oldest child No. 171, on March 4–5, 1916, was the longest continued, observations being made for over 11 hours after the food had been taken. Here, 2½ hours after food, the metabolism was 629 calories, rising an hour later to 647 calories, thereafter falling continuously until two minimum periods of 545 and 555 calories are found at 9 and 11 hours, respectively, after the food had been taken. If we consider the absolute minimum of 545 calories as basal, then the 647 calories, or the maximum heat production, represents an increase of 102 calories, or about 20 per cent, due to the influence of food. But this increase is relatively soon after feeding. The pulse-rate likewise shows a distinct tendency to fall off after the first rise due to the taking of food. The average value of 550 calories, which may be taken as the basal value, was determined, roughly speaking, 10 hours after the last meal.

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[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 47.

An examination of the chart for No. 171 (see fig. 16, page 124) shows that at the age of 13½ months there is a decided break in the line for the total calories, indicating a fairly low value at that time. The period of observation is considerably longer than that for most of the children in the series. It is therefore quite likely that, had the experiment been shorter, the point would more closely correspond to the general trend of the curve. But great stress should not be laid upon individual variations from day to day or from period to period.

On April 17–18, 1916, a long experiment was made with the infant No. 123, in which the child took food containing but 60 calories of energy. The metabolism was thereafter measured continuously for over 9 hours. While the absolute minimum value of 312 calories was found in the last period, the values for the last 2 hours indicate relative constancy. The maximum of 378 calories, which occurred 2 hours and 9 minutes after food, is equivalent to an increase of 66 calories above the minimum, or, roughly speaking, 20 per cent. The pulse-rate shows a general tendency to decrease after the maximum metabolism is reached, although the minimum pulse-rate is not coincidental with the minimum metabolism.

The series of observations with No. 131 continued for 9½ hours after food. The amount of food taken was insignificant in quantity and energy content, and the minimum value actually appeared about 4½ hours afterwards. The maximum value (391 calories) was found 9½ hours after food, or some 5 hours after the minimum value appeared. The great increase in the pulse-rate is wholly inexplicable, for the kymograph records indicate activities of but I and II, and the subject was presumably asleep. We have no explanation for these unusual figures.

With the other children, shorter observations were the rule after food. With No. 127, on April 20–21, 1916, five feedings were given, the observations after the first feeding continuing without break for 5 hours and 31 minutes. The absolute minimum of 255 calories was found about 5 hours after food. As the maximum value, which was obtained 1 hour 41 minutes after the third feeding, was 336 calories, there was a maximum rise of 81 calories, or approximately 30 per cent. Singularly enough, there was no marked change in the pulse-rate, the maximum increase being but a few beats.

The series of observations with No. 115 after the two feedings agree very satisfactorily, although the question of the actual basal value is in doubt, since this must be taken as but 3 hours and 11 minutes after the second feeding. The total increase on this basis is, therefore, 66 calories, or about 22 per cent above basal.

The observations with the other children were approximately 3 to 6 hours in length and usually indicate the minimum at the end of the period of observation, with maximum increases shortly after food was taken, these corresponding to not far from 20 to 30 per cent with most of the children. Of special interest with No. 119 is the fact that in the second feeding the energy in the food was almost three times that in the first feeding, and under these conditions a distinctly higher metabolism was noted. If we accept the basal value as 369 calories, which was obtained 5 hours and 41 minutes after the feeding of 80 calories in breast milk, we find an increase of 108 calories 1 hour and 50 minutes after the second feeding of breast milk with an energy content of 210 calories. This increase after the second feeding corresponds to about 29 per cent, as compared with the maximum increase of 34 calories, or 9 per cent, 1 hour and 8 minutes after the first feeding of a very much smaller amount of breast milk. With No. 140, who was the same age as No. 119, the energy content of the milk in the first feeding was 70 calories, while that of the second feeding was 170 calories. Here the increase due to the larger amount of milk was very slight, if any. It is also worthy of note that No. 136, after a second feeding, showed a maximum heat production no greater than that found after the first feeding, although the second feeding had an energy content four or five times larger than that of the first.

From an inspection of the data in table 23 it is clear that in most instances the absolute minimum values were not found before 8 to 9 hours after the last food. In nearly every one of the long series of observations the minimum values occur at or near the end. An exception to this is No. 131 in the observations on April 19–20, when approximately the minimum was found 4½ hours after the food. The energy content of the food in this case was, however, but 50 calories. Numerically the same conditions hold with regard to the observations on March 11–12, 1916, with No. 136. It is probable, therefore, that with as small an amount of food as 2 or 3 ounces of breast milk, with an energy content of approximately 50 calories, the metabolism is nearly basal at the end of 4 hours. With larger amounts of food the stimulating effect may persist for 9 or 10 hours.

It has been currently believed that the influence of food is considerably smaller with children than with adults and that the protein utilized for growth does not participate in the stimulating action formerly termed "specific dynamic action." Frankly, we were misled in some of our earlier observations by this belief, but the evidence here presented certainly gives no indication of a material lessening in the influence of food. Indeed, the general conclusion to be drawn from these data is that the influence of food upon the metabolism of infants is wholly comparable to that noted with adults. This renders all the more potent our contention that basal metabolism measurements with young children are not ideal in the commonly accepted definition of the term basal as applied to adults, since they are not made under conditions which preclude the stimulating action of food.

A rough assumption may be made that the basal metabolism as measured in our series of experiments is, in practically every instance, from 8 to 15 per cent higher than the true basal. This fact must be clearly recognized in the subsequent analysis of the general trend of the metabolism for children of varying ages. In the light of the variations shown in table 23, however, the direct application to our data of this percentage correction is not justifiable. Consequently, until further observations are made upon the quantitative effects of food on the metabolism of children, one can only emphasize the fact that the younger the child is, the greater is the deviation from basal towards a higher measurement of the metabolism.

It is a matter of regret that the influence of food was not studied with older children, but since it has been made clear that the basal values are too high, especially with the younger children, it is not impossible that these high values may, when corrected, equalize the values for heat production per square meter and bring them more in accordance with those found with adults. On the other hand, it would appear that if a correction were applied for children 6 months and under, it would only further distort the comparison curves for the metabolism. (See discussion of these curves in a subsequent section, page 176.) Final treatment of these curves, *i. e.*, in comparisons of children ranging in age from birth to puberty, and particularly in comparisons of children with adults, must be subject to the possibility of a correction to obtain the true basal. On the one hand, there will be a distinct objection to establishing a so-called correction on relatively few long experiments; on the other hand, there will be a distinct objection to comparing true basal values with the basal values of youth which are too high as a result of previous food. Except in cases of great weakness and probably disease, no metabolism values for youth may be considered as *under* basal, the tendency always being for such values to be *above* rather than below true basal.

Aside from the physical difficulties met with in attempting to secure measurements of the metabolism of children under true basal conditions, we have to deal with the possibility of an incipient acidosis. With adults, complete fasting soon produces a reduction in the store of glycogen and shortly thereafter acidosis sets in. The earlier experiments of Schlossmann and Murschhauser[1] seemed to show that this acidosis appeared much earlier with children than with adults. Experience in this laboratory, both with a fasting man[2] and with diabetics,[3] indicates strongly that the metabolism is noticeably stimulated by acidosis. As has been shown in other publications, it becomes a serious problem to decide upon the exact point when the stimulating effect of food ceases and the stimulus of acidosis begins. Even with adults this point has never been sharply defined, although from the general trend of metabolism during long experiments it appears that a minimum is reached not far from 10 to 12 hours after the last food is taken, unless the last meal was particularly rich in protein. Since one may designate the measured metabolism of these younger children only as approximating basal, comparisons between these values and true basal values for adults must be made with extreme caution.

THE ELEMENT OF NOVELTY IN MEASUREMENTS OF METABOLISM.

Throughout our entire series of experiments we were frequently confronted with the question as to how much of a rôle the element of novelty played in the determination of metabolism. Naturally, when the children went into the respiration chamber for the first experiment, their attitude toward the apparatus was somewhat different from that in the second experiment. While every effort was made to accustom the children to seeing the apparatus in working order and to assure them that there was nothing distressing or uncomfortable in the experiments, the novelty of being placed inside the respiration chamber might conceivably affect the basal metabolism; hence values secured on the first day might be looked upon as aberrant.

For a strict comparison of the results obtained under the two conditions, it is important in the first place that the two days be reasonably close together, so as to eliminate the factors of age and weight. Secondly, the periods for comparison must be of the lowest order of activity; that is, the child should preferably be in complete repose in both periods. After a careful scrutiny of our data, we have selected a number of experiments with children of both sexes and varying ages, which give suitable data for such comparison. These are brought together in table 24, which shows the heat production on the 24-hour

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[1] Schlossmann and Murschhauser, Biochem. Zeitschr., 1913, 56, p. 396.
[2] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 365.
[3] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, pp. 125 and 134.

TABLE 24.—*Comparison of metabolism and pulse-rate in first and second experiments with children.*

Subject No.	Age.		Date.	Heat (computed) per 24 hrs.		Pulse-rate.		Relative activity.
				Amt.	Diff.	No. of beats.	Diff.	
Boys:	*yrs.*	*mos.*		*cals.*	*cals.*			
192......	5	7	May 21, 1919	866		90		II, I
			May 22, 1919	962	+ 96	89	− 1	I, II
194......	5	9	Mar. 19, 1918	876		85		I, I
			Mar. 22, 1918	830	− 46	87	+ 2	I, I
204......	7	2	Mar. 29, 1919	999		81		I, II
			Apr. 1, 1919	908	− 91	86	+ 5	I, I
209......	7	10	Mar. 1, 1918	1,094		83		I, I, II
			Mar. 18, 1918	1,096	+ 2	74	− 9	I, I, II
228......	9	10	Feb. 5, 1919	1,241		85		I, II, I
			Feb. 6, 1919	1,215	− 26	75	−10	II, II
235......	10	7	Feb. 19, 1919	1,063		93		I, I, I
			Feb. 20, 1919	1,056	− 7	84	− 9	I, I, I
242......	11	.	Nov. 25, 1918	1,215		87		II, II
			Nov. 27, 1918	1,186	− 29	88	+ 1	I, II
246......	11	6	Feb. 6, 1919	1,320		70		I, II
			Feb. 7, 1919	1,314	− 6	64	− 6	I, I
250......	12	2	June 24, 1918	1,355		71		I, II, II
			June 27, 1918	1,211	−144	61	−10	I, II, II
256......	12	9	Feb. 20, 1918	1,365		87		I, II
			Feb. 23, 1918	1,290	− 75	72	−15	II, II
258......	13	8	Apr. 17, 1919	1,529		66		I, I
			Apr. 18, 1919	1,504	− 25	62	− 4	I, II
259......	14	1	May 6, 1918	1,260		78		I, I
			May 8, 1918	1,220	− 40	66	−12	I, I
260......	15	.	May 1, 1919	1,417		74		I, I, II
			May 6, 1919	1,431	+ 14	71	− 3	I, I, I
Average:								
1st day ..	....		....	1,200		81		..
2d day...	....		....	1,171	− 29	75	− 6	..
Girls:								
178......	2	11	Mar. 19, 1918	572		84		I, I, I, I
			Mar. 21, 1918	574	+ 2	91	+ 7	I, I, I
189......	5	3	Feb. 20, 1919	875		80		I, I
			Feb. 21, 1919	831	− 44	78	− 2	II, I
220......	9	1	Apr. 11, 1918	1,031		101		II, II
			Apr. 12, 1918	996	− 35	97	− 4	II, II
225......	9	5	Jan. 22, 1919	954		88		I, I, I
			Jan. 23, 1919	957	+ 3	82	− 6	I, I, II
238......	10	10	Apr. 26, 1919	987		89		I, I, I
			May 3, 1919	1,103	+116	81	− 8	I, I, I
251......	12	2	Mar. 8, 1919	1,027		79		I, I, I
			Mar. 11, 1919	1,042	+ 15	76	− 3	I, I, I
Average:								
1st day ..	....		....	908		87		
2d day...	....		....	917	+ 9	84	− 3	..
Gen. average:								
1st day ..	....		....	1,108		83		
2d day...	....		....	1,091	− 17	78	− 5	..

basis for the first and second days of observation, the pulse-rate, and (to indicate the degree of repose) the activity as estimated from the kymograph records. To indicate any variations due to sex, the data have been grouped separately for boys and girls.

With the majority of the subjects the observations were made on succeeding days, and with few exceptions not more than three days apart. These exceptions were Nos. 209, 238, and 260, with whom the observations were made 17, 7, and 5 days apart, respectively. The agreement in the values for the heat production for the two days is, in most cases, reasonably close. The results for the second day are, in many instances, lower than those for the first day, but the reverse is likewise true, so that, taking the plus and minus signs into consideration, one may state that the general average difference between the first and second day for all of the children is but −17 calories. Bearing in mind the difficulty of estimating relative activity from day to day, especially at the lower grades of activity, we find that the records of the relative activity in the last column of table 24 indicate that the average activity on the two days was equal.

Of special significance, however, is the pulse-rate, both when compared for the first and second days of experimenting and particularly when compared with the value for the total heat production. In the majority of instances the pulse-rate is lower on the second day than on the first day, the average of the values for all of the children on the second day being 78 beats per minute as compared with 83 beats on the first day. In many cases the pulse-rate is notably lower on the second day. The influence of "training," so to speak, is thus definitely towards a decidedly lower pulse-rate. A few instances of a higher pulse-rate on the second day occur, these being found with three boys, Nos. 194, 204, and 242, and with one girl, No. 178. The largest change is with the boy No. 256, whose pulse-rate fell from 87 to 72, or a total change of 15 beats. Changes of 9 or 10 beats are noted in several cases, especially with the boys. With these larger pulse-rate changes, there is in most cases a corresponding change in the metabolism, a fall in the pulse-rate being accompanied by a downward tendency in the metabolism. The changes are, however, by no means uniform, and the reverse is not infrequently found, namely, a lowering in pulse-rate with a slight increase in metabolism. This lack of harmony between pulse-rate and metabolism, which is more particularly evident with the girls, is sufficient to show that with children in the growing period there apparently is much less correlation between pulse-rate and metabolism with the same child than is found either with younger children or with adults.

When the data are examined with reference to their grouping as to sex, some difference is shown in the values. It might be expected that the boys would give results for the second day but little, if any, lower than for the first day, as they would naturally be less apprehensive and sensitive to outside influences than the girls and even enjoy the novelty of the experience. The data, however, show that with the boys there was almost invariably a fall on the second day, but three cases out of the thirteen giving an increase. The pulse-rate also shows a fall in all but three cases, but no one of these three was simultaneous with the rise in the metabolism. Unfortunately, the data for the girls are somewhat meager as compared with those for the boys. With four of the six girls the metabolism rose on the second day, but with two of the girls the rise was insignificant. The pulse-rate almost invariably fell slightly. Neither the boys nor the girls show a difference in the comparison of results due to age. The slight changes noted between the two sexes must be considered primarily of a psychological and only secondarily of a metabolic nature.

The values in table 24 thus demonstrate that the element of novelty plays no appreciable rôle in the basal metabolism. This finding is in full accord with the recent series of observations by Hendry, Carpenter, and Emmes[1] on a group of medical students, and makes it seem all the more probable that the small amount of preliminary training considered absolutely essential for metabolism measurements may be reduced to a minimum. Apparently, with complete muscular repose, the influence on the pulse-rate of previous experience in the respiration chamber is, with children, of minor significance.

METABOLISM AS AFFECTED BY GROWTH.

GENERAL METHODS OF STUDY.

An ideal study of the metabolism of children from birth to puberty would be the continuous measurement of the same child at frequent intervals throughout this period of life. All past experience has shown that the physiological activities of a child can by no means be represented by a straight line or by a regular curve function, for there are gross irregularities which are inexplicably and inherently a part of physiological life. Accordingly it is necessary to base deductions not upon the analysis of the metabolism of one child alone, but upon the metabolism of several children. Hence we felt it our duty to obtain measurements for a number of boys and girls during as long a period of life as they were available. The children of wet-nurses could be more or less controlled from birth, but as each year passed they became more widely scattered, and consequently it was increasingly difficult to secure them for observation. But even under these conditions we were able to hold and to study a representative number of these children. In all, studies were made with 23 children over varying periods of time. In no instance, however, could we approximate the ideal of intermittent measurements from birth to puberty, for after three or four years of observation it became impossible to keep in touch with the children.

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[1] Hendry, Carpenter, and Emmes, Boston Med. and Surg. Journ., 1919, 181, pp. 285, 334, and 368.

While such a method of intermittent study may still be considered as the ideal method, since it not only supplies an index of the individual variations for the same child from age-period to age-period, but also variations for different children at the same age and weight, it became necessary for us, in the absence of "ideal" conditions, to rely upon the accumulation of a considerable mass of evidence for not only the 23 children who were studied more or less continuously, but likewise a large number of isolated observations on other children. This collection of more or less isolated data, when combined with the semicontinuous observations, makes possible the charting of a considerable mass of material regarding the metabolism of children in the period from birth to puberty, thus supplying an excellent index of the general trend of the metabolism of a child.

By this method of procedure it is perfectly legitimate to consider values obtained with the same individual with changes in age and weight of some magnitude as representative of a new child at the indicated age and weight. The basal metabolism of an adult, as measured from month to month and from year to year in the decade from 20 to 30 years of age, does not vary greatly as a result of a change in age, and there is usually in this time no material change in weight or height. With children, on the other hand, the rapid growth and changes in stature and weight make it wholly illogical to average the values found for any child during a considerable range in age and to consider that the result represents the true average value for that child. In other words, a child of 1 year is one individual, but a child of 1½ years is still another individual. Accordingly, in grouping the children for general consideration, a definite method of selection was followed in determining the degree of change in either weight or age which would make it desirable to consider the child as a new individual. (See page 131.)

In analyzing our experimental data, we naturally turn first to the picture presented by the results for individual children with whom observations were continued for several months or years. Following this treatment of the data, we may properly proceed to summary tables and charts giving the results for all of the children studied, including not only those data representing long periods of time, but also the shorter isolated determinations of the basal metabolism made upon a large number of children of different ages who were usually observed on but one or two closely following days.

METABOLISM DURING GROWTH AS SHOWN BY THE INDIVIDUAL CHILD.

Observations with Subject No. 145.

Of the 23 subjects that were studied over relatively long periods of time, No. 145 (a girl) has been selected for detailed treatment to indicate the method of procedure which was followed with all of the children. The data for this child are given in table 25. For complete record it has been necessary to include data for the body-weight, height, age, the estimated energy of food taken prior to the experiment, the length of time elapsing between the taking of food and the beginning of the first observation, the carbon dioxide produced per hour in the several successive experimental periods, the respiratory quotient, the average pulse-rate for each period, the relative activity as estimated from the kymograph records, notes as to whether the subject was asleep or awake, the total heat production (computed) per 24 hours, and likewise the heat produced per kilogram of body-weight per 24 hours and per square meter of body-surface per 24 hours. The relative activity is expressed on an arbitrary scale ranging from the greatest degree of repose (I) to the greatest activity (VI). The body-surface was determined by the Du Bois linear formula and direct measurements made upon the subject for practically every observation. As has already been pointed out, while ideally the observations should have been made without food in the stomach, this is an abnormal condition for young children. It will be noted that as the child grew older the length of time between the feeding and the beginning of the first experimental period lengthened, until it was finally between 4 and 5 hours long.

As indicated in the outline of the description of the experimental procedure, the carbon-dioxide production was directly measured for each experimental period. These periods were approximately 30 minutes in length. As it was impracticable to determine the oxygen consumption in periods as short as this, due chiefly to the difficulty in obtaining accurate measurements of the average temperature of the air inside the respiration chamber, we determined only the total consumption of oxygen for the entire sojourn of the child inside the chamber. Thus for four experimental periods, each of 30 minutes, the oxygen consumption would be determined only for the full 2-hour period of the experiment, and this total amount used in the computation of the respiratory quotient.

In most of the studies there was a preliminary period in which various adjustments were made and in which the oxygen consumption was not determined. During the preliminary periods the amount of carbon dioxide produced was almost invariably larger than in later periods, this being due to the activity of the child, who was frequently awake at this time. The carbon-dioxide production for these periods is likewise recorded in table 25, but the measurements of the oxygen consumption, which were used for computing the respiratory quotients, were made only in the main periods of the observation, *i. e.*, those represented by the values inclosed in brackets. It occasionally happened that, even during the preliminary period, the carbon-dioxide production was at a minimum. Thus, on April 2, 1917, the carbon-

TABLE 25.—*Results of observations on the gaseous exchange of No. 145 (girl).*

Date.	Age, height, and weight without clothing.	Estimated energy of food.	Time between feeding and observation.	Carbon dioxide produced per hour.	Respiratory quotient.	Heat (computed) per 24 hours.			Average pulse-rate.	Relative activity.	Remarks.
						Total.	Per kilogram.	Per sq. meter (Du Bois linear).			
1916		*cals.*	*h. m.*	*gms.*		*cals.*	*cals.*	*cals.*			
June 15	5 mos.; 62 cm.; 5.27 kilos.	80	1 30	4.78	0.84	337	64	1,109	111	I	Probably asleep.
				4.71		332	63	1,092	117	I	
				4.94		348	66	1,145	116	I	
				4.46		315	60	1,036	119	I	
June 16	5.22 kilos.	80	30	7.91	......	580	111	1,908	126	IV	
				4.38	0.80	321	61	1,056	117	I	Do.
				4.87		357	68	1,174	116	II	
				4.34		318	61	1,046	118	I	
				4.64		340	65	1,118	117	II	
				4.93		361	69	1,188	118	III	
Nov. 22	10 mos.; 70 cm.; 9.19 kilos.	160	1	8.70	......	608	66	1,310	117	II	Asleep.
				8.86	0.85	619	67	1,334	113	III	Probably asleep.
				6.78		474	52	1,022	117	I	
				8.01		560	61	1,207	112	III	
				8.23		575	63	1,239	120	VI	
Dec. 4	9.50 kilos.	130	30	7.64	......	511	54	1,099	102	II	Asleep.
				7.94	0.90	531	56	1,142	111	II	
				7.99		534	56	1,148	108	III	
				7.55		505	53	1,086	111	II	
				11.23		751	79	1,615	126	V	
Dec. 22	11 mos.; 72.5 cm.; 10.2 kilos.	150	0	8.26	......	543	53	1,042	110	I	Do.
				7.90	0.92	519	51	996	114	II	Do.
				7.80		513	51	985	111	I	Probably asleep.
				8.90		585	58	1,123	114	II	
				7.78		508	50	975	109	I	
				9.22		606	60	1,163	113	V	
1917 Jan. 11	1 yr.; 73.5 cm.; 10.5 kilos.	150	1	7.08	0.89	477	46	928	103	I	Asleep.
				8.88		599	57	1,165	113	II	Probably asleep.
				7.32		494	47	961	106	II	Asleep.
				8.49		573	55	1,115	113	II	Awake, then asleep.
Jan. 31	10.9 kilos.	260[1]	0	8.80	......	583	53	1,094	106	IV	
				8.27	0.91	548	50	1,028	105	II	Asleep.
				8.40		557	51	1,045	111	I	
				8.74		579	53	1,086	106	II	
				10.14	......	672	62	1,261	119	VI	
Feb. 19[2]	1 yr. 1 mo.; 76.0 cm.; 11.3 kilos.	470[3]	30	9.22	......	606	54	1,104	112	I	Do.
				8.59	0.92	564	50	1,027	113	I	
				9.09		597	53	1,087	118	I	
				13.86	......	911	81	1,659	136	V	
Mar. 15	1 yr. 2 mos.; 76.0 cm.; 11.8 kilos.	240[4]	30	10.40	......	701	59	1,247	118	VI	
				7.68	0.89	518	44	922	105	II	Do.
				8.53		575	49	1,023	110	II	
				8.73		589	50	1,048	104	II	
				10.84		731	62	1,301	.....	V	

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[1] Includes 120 cals. taken 4 hours before the observation.

[2] Rectal temperature at beginning of observation was 99.8° F.; at end, 100.5° F.

[3] Includes 100 cals. taken 3½ hours before the observation.

[4] Includes 100 cals. taken about 4 hours before the observation.

TABLE 25.—*Results of observations on the gaseous exchange of No. 145 (girl)*—Continued.

Date.	Age, height, and weight without clothing.	Estimated energy of food.	Time between feeding and observation.	Carbon dioxide produced per hour.	Respiratory quotient.	Heat (computed) per 24 hrs.			Average pulse-rate.	Relative activity.	Remarks.
						Total.	Per kilogram.	Per sq. meter (Du Bois linear).			
1917		*cals.*	*h. m.*	*gms.*		*cals.*	*cals.*	*cals.*			
Mar. 27	12.1 kilos.	320[1]	0	9.00	......	612	51	1,048	103	II	Asleep.
				9.00	0.88	612	51	1,048	101	II	Do.
				8.95		610	50	1,045	105	I	Probably asleep.
				8.83		601	50	1,029	108	I	
				9.46		644	53	1,103	108	III	
Apr. 2[2]	12.0 kilos.	140	0	8.73	......	589	49	1,026	109	I	Asleep.
				9.09	0.89	613	51	1,068	112	II	
				9.55		644	54	1,122	113	II	
				9.97		672	56	1,171	121	IV	
Apr. 20	1 yr. 3 mos.; 78.0 cm.; 12.5 kilos.	240[3]	1	8.61	0.87	591	47	998	105	II	Probably asleep.
				8.66		594	47	1,003	101	II	
				8.43		579	46	978	97	III	Asleep.
				9.49		651	52	1,100	105	IV	
May 15	1 yr. 4 mos.; 78.5 cm.; 12.6 kilos.	320[4]	30	9.24	......	618	49	1,035	100	IV	
				8.10	0.90	541	43	906	92	II	Probably asleep.
				8.65		578	46	968	97	III	
				9.58		640	51	1,072	100	V	
May 18	12.5 kilos.	310[5]	0	10.05	......	660	53	1,065	106	V	
				9.74	0.92	640	51	1,032	100	IV	
				8.25		542	43	874	99	I	Probably asleep.
				8.61		566	45	913	97	II	Asleep.
				10.14		666	53	1,074	108	VI	
June 20	1 yr. 5 mos.; 80 cm.; 13.4 kilos.	640[6]	30	10.51	......	709	53	1,142	108	III	
				9.30	0.98	627	47	1,010	103	I	Probably asleep.
				9.79		660	49	1,063	110	I	
				13.59		917	69	1,477	119	V	
June 21	13.4 kilos.	(7)	(7)	9.92	......	646	48	1,040	102	IV	
				8.67	0.93	565	42	910	98	II	Asleep.
				9.29		605	45	974	105	I	
				9.69		631	47	1,016	95	I	
Nov. 6	15.1 kilos.	170	30	9.93	0.92	653	43	978	84	I	Do.
				9.03		593	39	888	89	I	Do.
				9.96		654	43	979	91	I	Probably asleep.
				11.71		769	51	1,151	100	V	
Nov. 15	1 yr. 10 mos.; 86.5 cm.; 15.2 kilos.	310[8]	1 30	12.05	......	.....	.....	.....	109	VI	
				9.45	......	.....	.....	.....	87	IV	Asleep, sobbing.

[1] Includes 100 cals. taken about 3½ hours before the observation.
[2] Rectal temperature at beginning of observation was 100.5° F.; at end, 99.8° F. Bad diarrhea on two preceding days; cutting teeth.
[3] Includes 100 cals. taken about 4½ hours before the observation.
[4] Includes 100 cals. taken 4 hours before the observation.
[5] Includes 170 cals. taken 4 hours before the observation.
[6] Includes 230 cals. taken 4 hours before the observation.
[7] Energy of food not known. Probably at least 150 cals. were taken just before the observation.
[8] Includes 140 cals. taken about 5½ hours before the observation.

Table 25.—*Results of observations on the gaseous exchange of No. 145 (girl)*—Continued.

Date.	Age, height, and weight without clothing.	Estimated energy of food.	Time between feeding and observation.	Carbon dioxide produced per hour.	Respiratory quotient.	Heat (computed) per 24 hours.			Average pulse-rate.	Relative activity.	Remarks.
						Total.	Per kilogram.	Per sq. meter (Du Bois linear).			
1918		*cals.*	*h. m.*	*gms.*		*cals.*	*cals.*	*cals.*			
Jan. 18	2 yrs.; 90.0 cm.; 15.4 kilos.	170	5	12.74	......	......	......	....:	111	VI	
				12.48	......	......	......	......	93	IV	
Jan. 19	15.3 kilos.	120	5	8.40	0.86	582	38	841	80	I	Asleep.
				9.34		647	42	935	85	I	Do.
				11.24		779	51	1,126	103	III	
Mar. 5	2 yrs. 2 mos.; 91.0 cm.; 15.2 kilos.	90	5 30	7.99	0.89	539	35	797	72	I	Do.
				9.20		620	41	917	74	II	Do.
				10.30		695	46	1,028	85	III	Asleep, but waked
May 16	2 yrs. 4 mos.; 94.0 cm.; 15.8 kilos.	170	4 30	8.98	0.85	628	40	946	69	I	Asleep.
				8.55		598	38	901	67	II	
				9.88		691	44	1,041	70	I	
				13.46		941	60	1,417	96	VI	
May 22	15.7 kilos.	200	4	13.63	......	971	62	1,458	93	VI	
				8.16	0.83	581	37	872	69	I	Do.
				8.70		620	40	931	71	I	Do.
				8.94		637	41	956	73	III	Probably asleep.
Nov. 5	16.7 kilos.	210	4	13.22	......	969	58	1,400	100	VI	
				9.92	0.80	727	43	1,051	78	I	Asleep.
				9.10		667	40	964	76	II	Do.
				11.60		851	51	1,230	78	III	Awake, then asleep.
Nov. 13	2 yrs. 10 mos.; 96.5 cm.; 16.4 kilos.	280	4	14.38	......	1024	62	14,95	93	VI	
				9.18	0.83	654	40	955	76	I	Asleep.
				7.98		568	35	829	71	I	Do.
				10.60		755	46	1,102	83	IV	
1919 Jan. 16	3 yrs.; 97.5 cm.; 17.0 kilos.	200	3 30	10.89	......	761	45	1,119	93	V	
				9.26	0.85	647	38	952	75	I	Do.
				12.28		858	51	1,262	77	IV	
Jan. 17	16.8 kilos.	220	4 30	10.02	0.80	735	44	1,081	71	I	Do.
				9.56		701	42	1,031	76	III	Asleep, but restless.
				9.36		686	41	1,009	73	I	Asleep.
				11.74		861	51	1,266	86	V	
Mar. 10	17.5 kilos.	234	4	13.27	......	927	53	1,324	94	VI	
				9.86	0.85	689	39	984	71	I	Do.
				9.58		670	38	957	71	III	Asleep, then awake.
Mar. 17	3 yrs. 2 mos.; 98.5 cm.; 17.5 kilos.	254	4	9.96	0.82	716	41	1,036	72	II	Asleep.
				8.94		643	37	931	67	I	Do.
				14.50	......	1043	60	1,509	97	VI	
June 13	3 yrs. 5 mos.; 101.5 cm.; 17.5 kilos.	319	4 30	11.50	......	789	45	1,126	88	III	
				9.28	0.87	637	36	909	72	I	Do.
				9.94		682	39	973	72	I	Do.
June 14	17.4 kilos.	249	4	12.09	......	924	53	1,300	88	V	
				10.38	0.76	793	46	1,115	66	I	Do.
				9.38		717	41	1,008	70	I	Do.

dioxide production in the preliminary period was 8.73 grams,[1] while the lowest during the subsequent periods was but 9.09 grams, even when the child was asleep. But this case is exceptional.

In the first observation with No. 145, that of June 15, 1916, the carbon dioxide produced in the first three periods varied only from 4.71 to 4.94 grams per hour. This is an astonishingly good agreement between periods and is in large part explained by the fact that the relative activity (indicated on an arbitrary scale) was I in all three of the periods and the child was probably asleep the entire time. Since the carbon dioxide values agreed so well, as a natural consequence the values for the computed heat for these three periods likewise agree well with each other. The carbon-dioxide production and heat for the fourth period were somewhat lower than for the other periods and thus represent the absolute minimum as determined for this day.

Before further consideration of the data in table 25, the possible errors entering into the measurements for any given period should be pointed out. For example, the measurement of the carbon-dioxide production for the individual periods is based upon the increase in weight of a set of absorbing bottles containing soda-lime and sulphuric acid. This requires the weighing of the bottles at the beginning and the end of each period. While all such weighings are verified by a second observer, an error in either one of these weights will obviously affect the value for the carbon-dioxide production for that period. Such a method does not admit of duplicate determinations for any period—a palpable defect. While this is true of practically all modern methods in which a respiration chamber is used, *i. e.*, either the total amount of carbon dioxide is measured only by one absorbing train or, if duplicate gas-analyses are made of samples taken from an air-current, but one main meter or spirometer measures the air-current, still, in considering the carbon-dioxide production for any *individual* period, such possibility of error must be borne in mind.

On June 15 the minimum heat production of 315 calories per 24 hours found in the fourth period is reasonably well confirmed by the second period with 332 calories per 24 hours, which is about 5 per cent higher. An average of these two figures would therefore give the most probable basal value for the child on this day. Since, however, we have an actually determined value of 315 calories, it is clear that, aside from technical errors, this heat production must be the basal or minimum heat production. In general, it may be said that the minimum basal metabolism is that actually observed, barring technical errors. We are then specially interested in evidence to prove the probability of a low value. Specifically, is 315 calories the real minimum value, or shall we tacitly admit the probability of technical errors and average the two lowest periods? Obviously, if 315 calories had been the result of duplicate simultaneous determinations, its validity could hardly be questioned.

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[1] In table 25 it seems desirable for purposes of comparison to represent the carbon-dioxide production on the basis of one hour rather than for the actual time of observation.

In an earlier communication[1] we emphasized strongly the relationship observable between the pulse-rate and the total metabolism. The pulse-rate for the four periods in this experiment varied only between 111 and 119. In the earlier observations just referred to, special stress was laid upon the countings of the pulse-rate to secure a sufficiently large number of counts to use for comparison with the metabolism which was simultaneously determined. In the present studies the records of the pulse-rate were necessarily subordinated in many instances to other technique. The average of 111 for the pulse-rate in the first period does not, therefore, necessarily represent the same number of counts as does the average of 119 for the fourth period. Effort was made, however, to secure a sufficient number of counts to give a representative average. In this observation the lowest carbon-dioxide production per hour (that of the fourth period) occurred when the pulse-rate was actually the highest. Judging from these data alone, the correlation between pulse-rate and metabolism is by no means positive and gives no further evidence of the validity of the value for the metabolism in this fourth period.

A second observation of 6 periods was secured on the next day (June 16). The high carbon-dioxide production for the preliminary period of 50 minutes (which is here given as 7.91 grams per hour) is readily accounted for by the activity in this period represented by the arbitrary designation IV. An accentuation of the pulse-rate is also found in this period, with a rate of 126 beats. The agreement in the carbon-dioxide production for the several periods of the main experiment is reasonably close, the values ranging from 4.34 to 4.93 grams per hour. The two lowest values, 4.38 and 4.34 grams, were coincidental with periods in which the activity was but I. For this day it is obvious that 4.34 grams of carbon dioxide, or from 318 to 321 calories, may justifiably be considered as the minimum. This amply confirms the single low value of 315 calories noted for the fourth period of the day before. While, therefore, the value for the last period on June 15 gave a true measure of the basal metabolism on this day, it has far greater weight from its substantiation by the values found in the two periods on June 16.

There was an interval of 5 months between the observation of June 15 and the next on November 22, during which there was a considerable increase in the length and weight of the child. The higher values for the carbon dioxide are thus easily explained by these increases. On November 22 we have but one period with the lowest grade of muscular activity. In this period the carbon-dioxide production was 6.78 grams per hour, corresponding to a heat production of 474 calories per 24 hours or 52 calories per kilogram of body-weight. It is unfortunate that no other period confirms this low value and that no test was made until December 4, nearly 2 weeks later. On this latter date no values are found so low as the minimum for November 22, although one period gives 505 calories per 24 hours or 53 calories per kilogram of body-weight[1] as compared with 52 calories observed on November 22. It is not unreasonable to consider that these two periods verify each other.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 130.

In analyses of the period values in these experiments, it is evident that verification by similar figures on another day or duplicate periods on the same day are highly desirable for establishing the true minimum metabolism. But this is by no means possible in every day's experimentation. Uncontrollable activities of III or more immediately rule out estimates for minimum values.

Frankly, the pulse-rate does not give invariably so close a correlation with the activity and the metabolism as we had expected. Thus, with the low period on November 22, the pulse-rate was 117, while in the most active period it was but 120. The respiratory quotients in the first four observations with this child range from 0.80 to 0.90 and are fully in line with the quotients which might be expected from the character of the diet. No abnormalities in the respiratory quotients are to be seen in the entire series, save that the low value of 0.76 in the last observation on June 14, 1919, is unusual.

An examination of the figures for the carbon-dioxide production as the observations progressed, giving due regard to the variations in activity, shows that the carbon-dioxide production during periods of minimum activity gradually increased as the age, height, and weight increased. With this child, at least, the minimum or basal metabolism for any given day is usually marked sharply.

The only experimental factor which varies in this series of observations, other than that of activity, is the food, as the amount taken, the character of the food, and the time between feeding and the first observation differ more or less on the several days. Theoretically the stimulus to cellular activity and to the metabolism increases with the increase in the amount of food and with the shortening of the interval between the taking of food and the beginning of the observations. Practically, when one attempts to correlate the amounts of food given, its character, and the length of time prior to the observation, it is only with difficulty that clear evidence can be found of the influence of food upon the basal metabolism. At first sight it would seem that this point is illustrated by the data for January 31, 1917, and those three weeks later (February 19). In one instance food containing 260 calories was taken immediately before the observations began; in the other, food containing 470 calories was given 30 minutes before the observations. The carbon-dioxide production and total heat production on February 19 are noticeably greater than those for January 31, but owing to a coincidental increase in body-weight, the heat production per kilogram of body-weight and that per square meter of body-surface are practically unaltered.

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[1] When the body-weight changes without material change in age, comparisons are best made on the basis of equal units of weight.

The pulse-rate for February 19 is distinctly higher on the average than on January 31, although in both observations the subject is reported as being asleep, with, if anything, the lesser activity on the second day. A complicating circumstance here is the fact that on February 19 there was a slight rise in rectal temperature, the record at the beginning of the observations being 99.8° F. and that at the end 100.5° F. The possible influence of food and the possible influence of a slightly febrile state are thus commingled and no sharp deductions can be made.

The influence of a slightly febrile temperature seems to be more marked upon the pulse-rate than upon the metabolism itself. On the two days when slightly febrile temperatures were noted, namely, on February 19, and April 2, 1917, the pulse-rates were noticeably higher than on the days immediately before or after. A corresponding increase in the metabolism is not always definitely noted. Still, the very fact that the pulse-rate was so obviously disturbed by this slight rise in temperature makes it all the more important to avoid the use of observations when the body temperature is even slightly febrile, especially in comparison experiments.

Perhaps one of the most pronounced instances of the influence of food is that shown by comparing the tests of May 18 and June 20, 1917. In the second observation it would appear as if the influence of food was clearly present, although the minimum value of 47 calories per kilogram of body-weight is but 10 per cent above the minimum of May 18. After the age of 2 years, the food was almost invariably taken 4 to 5 hours prior to the observations and hence may be considered as of comparatively little effect. After that age, the calories in the food represent not far from one-third to one-fifth of the daily requirement. Experience with adults would imply that at the end of 4 hours the peak of the stimulating effect of food would have been considerably passed. In none of these observations, therefore, have we the ideal condition of the post-absorptive state. The fact that in most cases the observations were made with the child asleep, and that in many instances, especially in the later years, the food had been given 4 or 5 hours before, undoubtedly minimizes and compensates the influence of the ingestion of food. Still, in any comparison of the metabolism of children at varying ages, it must constantly be borne in mind that food is almost always taken just prior to a test with children under 2 years of age and that 4 or 5 hours may elapse between the taking of food and the beginning of the metabolism measurements for the older children.

On examining the estimates for relative activity in the last column of table 25, one finds that the observations rarely show days when no periods with an activity of either I or II are available. In only two instances (November 15, 1917, and January 18, 1918) does the factor of persistent restlessness appear. The data for these two days are included in the table, however, to give a complete record of the observations with this child. Furthermore, the values for the carbon-dioxide production and the pulse-rate for these active periods are not without interest.

Almost invariably the high activities (IV, and particularly V and VI) are accompanied by a very great increase in the metabolism and likewise an increase in the pulse-rate. The periods with activities V and VI usually correspond to the maximum heat production. But absolute reliance must not be placed upon these estimates of activity from the kymograph records, for not infrequently anomalous figures appear. Thus, on November 22, 1916, the last period has an activity of VI, with a total metabolism of 575 calories, which is exceeded by the first two periods of the day, and yet activities II and III are recorded for these periods. As a rule, however, the metabolism is approximately proportional to the activity, and this factor is a valuable index of the metabolism of a subject. The pulse-rate is a like valuable index, but taken by itself it is at times, especially with youth, very unreliable. The carbon-dioxide production, the pulse-rate, and relative activity taken together make the selection of minimum periods rarely a matter of great difficulty. When these are confirmed by sustaining figures on days immediately preceding or following, the base-line becomes even more definitely fixed.

Occasionally low and seemingly aberrant figures appear in table 25. Thus, in the first experimental period on March 15, 1917, but 7.68 grams of carbon dioxide were measured, an amount corresponding to but 44 calories per kilogram of body-weight. This value is considerably lower than those found for the next three or four days of observation; yet on April 20, 1917, a heat production of 46 calories per kilogram is noted, and it is probable that 7.68 grams of carbon dioxide or 44 calories per kilogram of body-weight represents the true minimum value for March 15.

While the observations with the child No. 145 were, with one exception, larger in number than those with any of the other children, they are given here in detail primarily to indicate the method of study and analysis of the results. Since we are dealing with an organism that is continually increasing in age, length, and weight, a comparison of the metabolism values from day to day is best made by some graphic form of representation, such as a chart. This comparison has been made in figure 15, in which, to avoid confusion from a multiplicity of points, the most important (19 in all) have been selected for plotting.

In selecting the points for a chart to show the changes in the metabolism of an individual as the age increases, values for single days could not advantageously be used. They were accordingly not infrequently averaged, most of the points in this chart being made up of one or more days. Since a selection of data was necessary, which is always undesirable in the preparation of scientific reports, we have given in table 26 a summary of the actual minimum values and averages used in figure 15, to show exactly how these points were derived. Many of these values were likewise used on the general charts or group summaries (see figures 23 to 47, pages 135 to 175), those not so used being indicated by an asterisk. Thus, this child (No. 145) appears on the general charts nine times, or as nine different individuals, since at all of these nine points there was sufficient difference in either age or weight to meet our requirements for the designation of children as new individuals. We believe such points may properly be included in any general chart in which values for a number of children are represented.

For all of the *individual* charts (see figures 15 to 21, pages 114 to 130), which were prepared primarily to indicate the *basal* metabolism at different ages of the same child, well-substantiated figures were invariably sought. In some instances it may be a little difficult for the reader to see why certain values are not selected or included in an average. For instance, the values obtained with the child No. 145 on June 21, 1917, appear in figure 15, while those for June 20, 1917 (see table 25), do not, although one might naturally expect that an average for these two days would be used. Since, as poined out on page 106, the possibility of an analytical error is always present, it can be seen that the value of 565 calories for the first period on June 21 is not substantiated, except that it agrees essentially with the low values on May 18. The minimum value on June 20 (627 calories) is noticeably higher than that found in two periods on June 21. Consequently, it was necessary here to make a selection of material, and it seemed logical to choose for charting an average of the three periods on June 21, *i. e.*, 600 calories, rather than to use the unsupported minimum.

On March 5, 1918, a very low value of 539 calories is noted in the first period, with 620 calories in the following period. Here again we have an unsupported minimum figure which it seems unwise to include, as there was a change in age of only 4 months, *i. e.*, January to March. The value of 620 calories, although fitting well into the general curve,

TABLE 26.—*Minimum heat production of No. 145 (girl).*[1]

Date of experiment.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kilo.	Heat (computed) per 24 hours. Per sq. m.
1916.		*kilos.*	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
June 15....	....	5.27	......	......	119	315	60	1,036
June 16....	....	5.22	......	......	118	318	61	1,046
Average..	5 mos............	5.25	62.0	0.304	119	317	61	1,041
Nov. 22....	10 mos. 1 wk......	9.19	70.0	.464	117	474	52	1,022
Dec. 4....	*10½ mos..........	9.50	70.9	.465	111	505	53	1,086
Dec. 22....	11 mos. 1 wk......	10.2	72.5	.521	109	508	50	975
1917.								
Jan. 11....	*11 mos. 3½ wks....	10.5	73.9	.514	103	477	46	928
Jan. 31....	*1 yr. ½ mo.........	10.9	73.2	.533	105	548	50	1,028
Feb. 19....	*1 yr. 1 mo.........	11.3	76.1	.549	113	564	50	1,027
Mar. 15....	1 yr. 2 mos.......	11.8	76.0	.562	105	518	44	922
Mar. 27....	*1 yr. 2 mos. 1½ wks.	12.1	75.8	.584	108	601	50	1,029
Apr. 20....	....	......	......	......	105	591	47	998
		......	......	......	101	594	47	1,003
		......	......	......	97	579	46	978
Average..	*1 yr. 3 mos.......	12.5	77.9	.592	101	588	47	993
May 15....	....	12.6	......	.597	92	541	43	906
May 18....	....	12.5	......	.620	99	542	43	874
Average..	*1 yr. 4 mos.......	12.6	79.0	.609	96	542	43	890
June 21....	....	......	......	......	98	565	42	910
		......	......	......	105	605	45	974
		......	......	......	95	631	47	1,016
Average..	1 yr. 5 mos.......	13.4	80.0	.621	99	600	45	967
Nov. 6....	....	......	......	......	84	653	43	978
		......	......	......	89	593	39	888
		......	......	......	91	654	43	979
Average..	1 yr. 9 mos. 3 wks..	15.1	86.5	.668	88	633	42	948
1918.								
Jan. 19....	*2 yrs............	15.3	90.0	.692	80	582	38	841
May 16....	....	15.8	......	.664	67	598	38	901
May 22....	....	15.7	......	.666	69	581	37	872
Average..	2 yrs. 4 mos.	15.8	94.0	.665	68	590	38	887
Nov. 5....	....	16.7	......	.692	76	667	40	964
Nov. 13....	....	16.4	......	.685	71	568	35	829
Average..	2 yrs. 10 mos.	16.6	96.5	.689	74	618	38	897
1919.								
Jan. 16....	....	......	......	.680	75	647	38	952
Jan. 17....	....	......	......	.680	73	686	41	1,009
Average..	*3 yrs............	16.9	97.4	.680	74	667	40	981
Mar. 10....	....	17.5	......	.700	71	670	38	957
Mar. 17....	....	17.5	......	.691	67	643	37	931
Average..	3 yrs. 2 mos.	17.5	98.5	.696	69	657	38	944
June 13....	....	......	......	......	72	637	36	909
		......	......	......	72	682	39	973
Average..	*3 yrs. 5 mos......	17.5	101.3	.701	72	660	38	941

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[1] Normal, breast-fed; adenoids removed at 1 yr.; developed to very large normal child.

NOTE.—The data indicated by asterisks (*) were not used on the general metabolism charts (figs. 23 to 47, pages 135 to 175) or on the anthropometric charts (figs. 5, 6, 8, 12, 13, and 14, pages 43 to 68) but were used, along with the other data in this table, on the individual chart for this child (fig. 15, p. 114).

is likewise not supported, although this is probably the true value for the basal metabolism.

These selections seemed desirable in preparing the individual chart for No. 145, and it is for the purpose of showing investigators the basis for these and similar selections that the detailed figures for this child are given in table 25. If there is disagreement with our selection of the values shown in table 26 and used in the chart, other data can be chosen, but according to our experience, the selected figures are the most probable and best experimentally substantiated values for the basal metabolism of this child at the various age-levels.

In the analysis of the figures in table 25, little attention can profitably be paid to the values of heat per kilogram of body-weight and per square meter of body-surface, other than to note that, in general, there is a disposition for the heat per kilogram of body-weight to decrease as the child grows older. An examination of the values for heat per square meter of body-surface shows very considerable variations. Those variations ascribable to activity (for which note indices in the last column of the table) should be completely disregarded in any careful analysis. Consequently, the detailed data do not lend themselves to a comparison of values from day to day, from month to month, or from year to year. It may be noted roughly that with high activity there is almost invariably a high heat production per square meter of body-surface, but since we are interested primarily in the basal metabolism of children, *i. e.*, the metabolism measured when activity is not present, those periods with high activity can have value only as indicating the possible maxima when the child is extremely restless. The distribution and range of the basal values can much better be studied by means of the chart.

The chart in figure 15 indicates the changes in body-weight, pulse-rate, total calories per 24 hours, calories per kilogram of body-weight, and calories per square meter of body-surface, from the age of 5 months to 41 months. Considering first the body-weight, since this, like the other children studied, was a normal child, we find the curve quite in line with that normally expected, namely, a definite progressive increase throughout the entire period, the most rapid period of change being from the fifth to the twenty-first month. The total calories, although showing considerable differences from time to time, range from 317 to 667 calories; in general the curve is reasonably parallel to the curve for body-weight. In other words, as the child regularly increased in weight, height, and age, the total calories per 24 hours likewise regularly increased.

With so rapidly changing an organism as a growing child, comparisons should be made at two ages or weights on some basis other than total calories. The two bases most commonly used by physiologists have been those corresponding to a unit of weight, *i. e.*, the calories per kilogram of body-weight, and to a unit of surface, *i. e.*, the calories per square meter of body-surface. These have both been charted, the former showing a distinct tendency for a downward trend from 61 calories at 5 months to an approximate level at 38 calories between the twenty-fourth and forty-first months. It thus appears that per kilogram of body-weight the heat production of the infant is considerably greater than that of a child from 2 to 3 years of age.

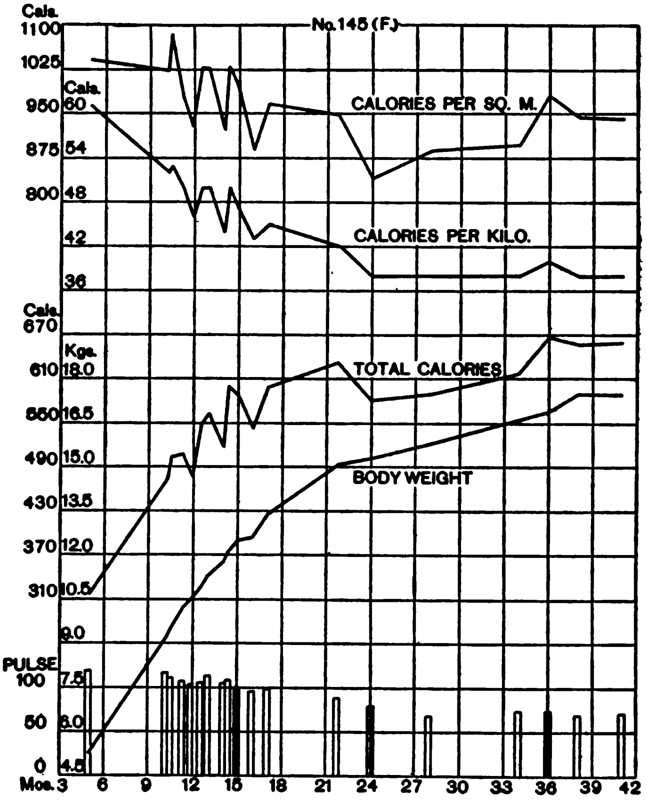

FIG. 15.—Body-weight, pulse-rate, and basal heat production per 24 hours (No. 145).

When the calories per square meter are charted (and it must be recalled that we have on this chart only values representing the minimum metabolism at the different ages) we find variations ranging from 1,086 to 841 calories. Although the curve is extremely irregular, there is a tendency downwards, with a slight rebound after 24 months. As this curve stands, it is apparently not so regular as that for the calories per kilogram of body-weight, and taken by itself gives very little evidence of a physiological law correlating the energy output and the body-surface of the child. It should, furthermore, be recalled that (in the case of this child, at least) the body-surface was not computed by the erroneous formula of Meeh, nor was it even computed up to 10 kg. by the more exact formula of Lissauer, but it was actually determined from an elaborate series of Du Bois body-surface measurements. Even with these most favorable conditions for comparing the surface of the body with the heat production, we find very great irregularity instead of the constancy hopefully predicted by earlier writers.

The individual blocks indicating the height of the pulse-rate show a tendency for this factor to decrease with increasing age, a low level being reached at not far from 27 months, with but slight fluctuations thereafter.

Were the observations of this series the only ones available for drawing final conclusions, the evidence accumulated in tables 25 and 26 and in figure 15 would warrant more refined analysis, with a more extensive series of deductions. The hint of great individual irregularities shown in all the curves except that of body-weight, and particularly the curve for calories per square meter of body-surface, would alone make us somewhat cautious in drawing general conclusions. Since 22 other subjects were studied (though not so extensively, as a rule, as in this particular case), it seems desirable first to consider giving the data individually by means of charts. These charts include children at ages ranging from below 5 months to more than 41 months, and of both sexes. Generalized conclusions may then be drawn from the whole series in addition to those tentatively drawn from the picture presented by the data for No. 145.

OBSERVATIONS WITH 22 CHILDREN DURING PERIODS OF 4 MONTHS TO 3½ YEARS.

As the detailed results for the other 22 subjects studied over relatively long periods would require considerable space for tabular presentation, it did not seem desirable to give the data in full, and the basal metabolism of these children is therefore shown by means of the curves in figures 16 to 21. Tables 27 and 28 give the data used in the charts for boys and girls, respectively. These tables were prepared primarily to show the data used in plotting the general group charts (figures 22 to 47, pages 133 to 175), but additional data employed in plotting the individual charts (figures 16 to 21) were likewise included. As in table 26, the data not used in the general charts are indicated by an asterisk, but all of the data in these tables appear in the charts in figures 16 to 21 for the individual children.

Two of these twenty-two children, Nos. 139 and 171, were studied during a period of time as long as that represented by the chart for No. 145, *i. e.*, approximately 3 years. The others were studied for the most part during periods of a few months or a year or two. Since the charts for Nos. 139 and 171 are strictly comparable with that for No. 145, at least so far as period of study and elaborateness of measure-

TABLE 27.—*Minimum heat production of boys at different ages.*

[Children normal unless otherwise stated. The data indicated by asterisks (*) were not used on the general metabolism charts for boys (figs. 22 to 45, pages 133 to 174) or on the anthropometric charts (figs. 3, 4, 7, 9, 10, and 11, pages 40 to 66), but were used, along with the other data in this table on the individual charts for these children (figs. 15 to 21, pages 114 to 130).]

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
[1] 6 (F.R.)	8 days	4.54	52.0	[2]0.283	124	191	42	675
[1] 27	8½ days	3.86	53.0	[2] .253	129	198	51	783
106	8½ days	3.83	53.0	[2] .252	108	163	43	647
107	10 days	3.38	51.0	[2] .232	124	163	48	703
108	11½ days	3.40	50.5	[2] .233	135	202	59	867
[1]112 (M.D.)	17 days	3.99	....	[2] .260	127	196	49	756
114	1 mo.	3.83	54.0	[2] .252	125	214	56	849
115	1 mo.	3.83	55.0	.243	118	186	49	765
	* 1½ mos.	3.91	....	....	127	200	51	791
	* 1 mo. 3 wks.	4.17	....	....	135	215	52	799
	* 2 mos.	4.38	....	....	125	229	52	881
	2½ mos.	4.71	58.5	.271	129	255	54	941
	4½ mos.	5.86	63.0	.338	124	296	51	876
	* 5 mos.	6.01	....	....	129	368	61	1,061
	* 5 mos. 3 wks.	6.45	....	....	124	350	54	992
	* 6 mos. 2 wks.	6.23	....	....	106	315	51	921
	7 mos. 3 wks.	6.83	65.0	.374	120	389	57	1,040
117	1 mo. 3 wks.	4.54	55.0	.273	108	227	50	830
118	1½ mos.	4.71	58.5	.278	124	232	49	835
	4 mos.	6.08	65.0	.338	121	339	56	1,003
119	1 mo. 1½ wks.	4.96	58.5	.313	126	268	54	856
	* 1 mo. 3 wks.	5.10	....	....	118	253	50	832
	4 mos.	6.00	64.5	.331	118	378	63	1,142
	* 4 mos. 3½ wks.	6.56	....	....	98	362	55	1,034
	6 mos.	7.21	67.5	.389	122	369	51	949
	* 6½ mos.	7.44	....	....	114	428	58	1,044
	* 7 mos.	7.82	....	....	118	438	56	1,082
	* 7½ mos.	8.08	....	....	118	463	57	1,132
	7 mos. 3½ wks.	8.51	70.5	.431	122	506	59	1,174
	1 yr. 1 mo. 3½ wks.	11.8	79.5	.535	125	684	58	1,278
	* 1 yr. 4 mos.	12.4	....	....	107	653	53	1,126
	* 1 yr. 4 mos. 1½ wks.	12.4	....	....	107	650	53	1,085
	* 1 yr. 6 mos.	12.6	....	....	108	664	53	1,116
	* 1 yr. 7 mos. 1 wk.	12.6	....	....	95	641	51	1,080
	1 yr. 8 mos.	12.5	85.5	.593	88	687	55	1,159
	2 yrs. 1 mo.	13.6	90.5	.624	94	717	53	1,149
[1] 61	2 mos.	4.60	56.0	[2] .285	138	233	51	818
[1]124 (L.L.)	2½ mos.	5.13	57.0	[2] .306	119	269	52	878
[3]125	2½ mos.	5.39	58.5	.320	117	285	53	891

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[1] Previously reported under initials given by Benedict and Talbot, Am. Journ. Diseases of Children, 1914, 8, p. 1. Data for boy designated by initials M. D. also reported by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914. Results for Nos. 6, 27, and 61 reported under the same subject number by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915.

[2] Lissauer surface.

[3] Certainly breast-fed. Probably many others were, but we are uncertain.

TABLE 27.—*Minimum heat production of boys at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
[1]126	* 2 mos. 1½ wks.	5.79	....	....	117	276	48	844
	2 mos. 3 wks.	5.90	60.5	0.333	105	267	45	802
	* 3 mos.	6.12	....	....	105	290	47	838
	6 mos.	7.49	66.5	.400	109	370	49	925
	7½ mos.	8.24	69.5	.422	103	413	50	979
128	3 mos.	6.32	61.5	[2] .352	117	296	47	841
[3]129 (E.F.)	3 mos.	7.07	62.0	[2] .380	111	311	44	828
[3]130 (A.S.)	3 mos.	6.02	63.0?	[2] .341	113	305	51	888
[1]132	3½ mos.	6.18	64.0	.344	119	318	52	923
[1]133	3 mos. 2½ wks.	5.81	62.5	.327	132	329	57	1,006
136	4½ mos.	6.70	67.5	.373	117	365	55	980
	6 mos.	8.19	71.0	.427	126	445	54	1,042
	7 mos.	8.93	73.5	.453	120	454	51	1,002
	* 7 mos. 1 wk.	9.08	....	....	103	461	51	1,034
	9 mos.	10.6	76.5	.509	121	588	55	1,155
	*10½ mos.	11.2	....	....	112	622	55	1,229
[3]137 (R.E.)	4½ mos.	5.04	60.0	[2] .303	114	324	64	1,070
[4]138	4½ mos.	7.98	68.0	[2] .411	132	414	52	1,007
	* 6 mos.	8.56	....	....	128	473	55	1,121
	10 mos. 3½ wks.	9.54	74.5	.453	111	577	60	1,274
	1 yr. 4 mos. 3½ wks.	10.1	79.0	.508	103	590	59	1,161
	* 1 yr. 6 mos. 2 wks.	10.3	....	....	106	592	57	1,128
	1 yr. 7 mos. 3 wks.	10.9	80.5	.526	120	656	60	1,247
	* 1 yr. 9½ mos.	11.3	....	....	98	645	57	1,166
	* 1 yr. 10 mos. 3 wks.	11.3	....	....	103	642	57	1,166
	1 yr. 11 mos. 3 wks.	11.8	82.0	.566	94	658	56	1,163
141	5 mos.	6.55	62.0	[2] .361	128	382	58	1,058
[5]142	5 mos.	9.14	67.5	.470	110	372	41	793
	* 6 mos.	9.21	....	....	101	340	37	702
	8 mos. 1½ wks.	10.7	70.0	.522	116	456	43	874
	* 9 mos. 1 wk.	10.6	....	....	102	437	41	825
	*10½ mos.	10.9	....	....	112	496	45	902
147	5 mos. 1½ wks.	6.50	63.0	.373	106	367	57	987
148	5 mos. 1 wk.	6.55	66.0	.379	111	347	53	916
	* 5½ mos.	6.66	....	....	113	391	59	1,000
	* 6 mos.	6.66	....	....	111	379	57	1,024
	* 6 mos. 1½ wks.	6.92	....	....	123	411	59	1,087
	7 mos.	7.39	68.0	.394	109	412	56	1,046
	8½ mos.	8.87	72.0	.435	108	467	53	1,074
	* 9½ mos.	9.15	....	....	111	512	56	1,145
	1 yr. ½ mo.	9.71	78.0	.458	115	537	56	1,173
	1 yr. 5 mos.	11.3	82.0	.521	105	559	50	1,073
[6]149 [3](H.T.)	5½ mos.	9.33	75.0?	[2] .457	101	420	45	912
[7]150	6 mos.	7.23	72.0	[2] .386	105	428	59	1,108
[8]153	6 mos. 1½ wks.	7.22	67.0	.388	107	378	52	976
	* 7½ mos.	7.87	....	....	109	396	50	966

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[1] Certainly breast-fed. Probably many others were, but we are uncertain.

[2] Lissauer surface.

[3] Previously reported by Benedict and Talbot under initials given, Am. Journ. Diseases of Children, 1914, 8, p. 1. Data for boys designated by initials E. F., A. S., R. E., and H. T. also reported by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914.

[4] Slow to walk because of weak musculature; flesh flabby.

[5] Flesh slightly flabby; breast-fed.

[6] Above average weight.

[7] Shortly recovered from cervical adenitis.

[8] Adenoids removed at 2 yrs.; backward mental development; breast-fed.

TABLE 27.—*Minimum heat production of boys at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
153	8 mos. 3 wks.	8.44	68.5	0.435	106	453	54	1,041
(cont.)	* 9½ mos.	8.56	......	......	107	484	57	1,078
	* 1 yr. 1½ wks.	8.77	......	......	124	547	62	1,159
	1 yr. 6 mos.	10.2	77.0	.505	99	553	54	1,095
	* 1 yr. 7½ mos.	10.3	......	......	105	606	59	1,139
	* 1 yr. 10 mos.	10.8	......	......	105	648	60	1,161
	2 yrs.	11.2	80.0	.553	106	657	59	1,188
	2 yrs. 5 mos.	12.5	84.0	.579	98	667	54	1,152
	* 2 yrs. 6½ mos.	12.9	......	......	103	664	51	1,139
	2 yrs. 9 mos. 3 wks.	13.7	87.0	.598	91	668	49	1,117
	* 3 yrs. 2 wks.	13.7	......	......	94	769	56	1,263
[1]154	6½ mos.	7.91	66.0	.434	126	452	57	1,041
155	7 mos.	6.54	68.0	.380	117	407	62	1,070
	* 7½ mos.	6.69	......	......	110	413	62	1,076
	10 mos.	7.56	71.5	.412	117	486	64	1,180
	2 yrs. 6 mos.	12.7	90.0	.568	107	711	56	1,252
	2 yrs. 10 mos.	13.3	93.5	.595	90	665	50	1,118
156	7 mos.	7.32	65.5	.419	126	457	63	1,092
[2]157 (P.W.)	7 mos.	7.11	64.0 ?	[3] .381	120	439	62	1,147
[4]158	7 mos.	7.48	66.5	.403	120	383	51	950
	* 7½ mos.	7.48	......	......	125	425	57	1,057
	* 8 mos.	7.41	......	......	101	377	51	936
	* 9 mos.	7.46	......	......	91	405	54	983
	11 mos. 3 wks.	8.48	70.5	.449	131	518	61	1,154
	* 1 yr. 1 mo.	8.76	......	......	124	535	61	1,168
	1 yr. 6 mos.	9.55	77.0	.483	116	586	61	1,213
	* 1 yr. 7 mos.	9.50	......	......	108	572	60	1,197
	* 1 yr. 8 mos. 3 wks.	9.94	......	......	114	612	62	1,195
	* 1 yr. 10 mos. 3 wks.	9.99	......	......	105	541	55	1,067
	2 yrs. 1 mo.	10.0	81.0	.510	83	588	59	1,153
	2 yrs. 6 mos. 1 wk.	11.7	82.0	.541	88	650	55	1,201
	* 2 yrs. 8 mos. 1 wk.	12.1	......	......	85	622	51	1,134
	2 yrs. 10 mos.	12.7	84.0	.562	79	623	49	1,109
	* 2 yrs. 10 mos. 1 wk.	12.7	......	......	84	671	53	1,192
	* 3 yrs. 1 mo.	13.1	......	......	83	720	55	1,274
	* 3 yrs. 1 mo. 1 wk.	12.8	......	......	75	719	56	1,255
[1]159	7½ mos.	7.03	66.5	.374	116	413	59	1,104
161	7½ mos.	6.70	67.5	.395	121	429	64	1,086
	9 mos.	8.09	70.5	.419	144	473	58	1,129
	1 yr. 2 mos.	10.1	77.5	.509	124	503	50	988
[5]164 [2](R.L.)	8½ mos.	7.58	71.0	[3] .398	115	455	59	1,140
[6]168 [2](R.S.)	9½ mos.	9.94	74.0	[3] .476	108	531	53	1,115
[2]170 (E.G.)	10 mos.	9.37	74.0	[3] .458	106	479	51	1,046
175	2 yrs. 5 mos. 1 wk.	12.6	82.0	.555	......	587	47	1,057
176	2 yrs. 5 mos. 1 wk.	12.3	87.5	.578	83	720	58	1,245
[6]177	2 yrs. 7½ mos.	14.6	88.5	.608	100	649	45	1,067
182	4 yrs.	15.5	94.0	.643	82	800	52	1,244
186	4 yrs. 9 mos. 1 wk.	19.3	110.5	.811	76	716	37	883
187	5 yrs. 3 wks.	20.6	111.0	.832	68	791	38	951

[1] Certainly breast-fed. Probably many others were, but we are uncertain.

[2] Previously reported by Benedict and Talbot under initials given, Am. Journ. Diseases of Childred, 1914, 8, p. 1. Data for boys designated by initials P. W., R. L., and E. G. also reported by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914.

[3] Lissauer surface.

[4] At 17 mos. had diarrhea; lost weight, then gained; had frequent colds; normal development.

[5] Approximately normal.

[6] Overnourished.

TABLE 27.—*Minimum heat production of boys at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
192	5 yrs. 6 mos. 3 wks.	18.8	106.0	0.758	90	866	47	1,143
[1]193	5 yrs. 7 mos. 3½ wks.	23.7	118.0	.903	70	855	36	947
194	5 yrs. 9 mos. 1 wk.	19.8	107.5	.820	86	813	41	991
197	6 yrs. 9 mos. 3 wks.	19.9	114.0	.795	99	925	47	1,163
[3]199	6 yrs. 10½ mos.	20.2	115.5	.812	72	843	42	1,038
[8]201	7 yrs. 3½ wks.	21.1	122.5	.865	83	864	41	999
	7 yrs. 3 mos. 2½ wks.	24.4	124.0	.928	75	1,021	42	1,100
202	7 yrs. 2 mos.	25.2	121.0	.940	74	944	37	1,004
204	7 yrs. 2 mos.	19.9	111.5	.820	73	838	42	1,022
[2]205	7 yrs. 2 mos. 1 wk.	21.3	117.5	.887	78	899	42	1,014
[1]209	7 yrs. 11 mos.	25.1	125.5	1.013	74	1,057	42	1,043
211	8 yrs. 1 mo. 1 wk.	26.8	129.0	1.072	78	1,033	39	964
212	8 yrs. 1 mo.	21.1	120.5	.888	69	785	37	884
[4]215	8 yrs. 2½ mos.	20.8	116.5	.845	94	984	48	1,165
217	8 yrs. 6 mos.	26.7	123.5	.971	80	1,097	42	1,129
[5]218	8 yrs. 7 mos.	24.7	128.5	.956	65	932	38	975
	9 yrs. 5½ mos.	26.8	133.5	.988	78	1,054	39	1,067
[6]222	9 yrs. 3½ wks.	25.0	122.5	.942	71	1,038	42	1,102
[7]223	9 yrs. 1 mo. 2 wks.	25.9	129.0	.991	86	1,011	39	1,020
[2]224	9 yrs. 3 mos. 3½ wks.	25.4	126.0	1.027	77	959	38	934
[6]228	9 yrs. 9 mos. 3 wks.	28.5	126.5	1.003	79	1,209	43	1,205
[6]229	9 yrs. 11 mos.	30.1	128.0	1.054	76	1,092	36	1,036
232	10 yrs. 4 mos.	28.1	127.0	1.087	80	1,037	37	954
[9]235	10 yrs. 7 mos. 1 wk.	30.3	134.0	1.088	85	1,015	34	933
236	10 yrs. 8 mos. 3½ wks.	31.0	132.5	1.084	76	1,147	37	1,060
237	10 yrs. 9 mos.	33.6	139.5	1.213	73	1,192	36	983
240	11 yrs. 1 mo. 1½ wks.	33.8	138.5	1.244	....	1,230	36	989
[9]241	11 yrs. 1½ mos.	30.6	136.0	1.100	77	1,086	36	987
242	11 yrs. 2 mos. 1½ wks.	26.8	126.0	.985	80	1,117	42	1,134
[6]243	11 yrs. 3 mos. 1½ wks.	37.9	149.5	1.256	69	1,282	34	1,021
[6]244	11 yrs. 4½ mos.	29.5	132.0	1.083	63	1,039	36	960
[10]245	11 yrs. 5½ mos.	31.7	135.5	1.165	61	1,213	38	1,041
246	11 yrs. 6 mos.	36.9	150.5	1.245	67	1,283	35	1,031
[2]247	11 yrs. 8 mos. 1 wk.	30.5	141.0	1.155	68	1,023	34	886
[2]249	11 yrs. 11 mos. 3 wks.	29.9	135.5	1.187	63	1,087	37	915
[6]250	12 yrs. 1 mo. 2½ wks.	41.0	150.5	1.370	61	1,211	30	884
252	12 yrs. 3 mos. 2 wks.	34.1	139.0	1.245	66	1,167	34	937
253	12 yrs. 7 mos. 3 wks.	30.4	140.0	1.085	73	1,163	38	1,072
254	12 yrs. 7 mos. 3 wks.	39.0	151.0	1.333	66	1,163	30	872
[11]255	12 yrs. 8 mos.	37.9	153.0	1.303	67	1,096	29	841
[2]256	12 yrs. 8 mos. 2½ wks.	32.8	137.5	1.221	72	1,246	38	1,020
[12]258	13 yrs. 8 mos.	50.8	159.5	1.494	63	1,481	29	991
[13]259	14 yrs. 1 mo.	38.2	151.5	1.335	61	1,200	32	899
[14]260	15 yrs. 1 wk.	39.0	147.0	1.300	72	1,401	36	1,079

[1] Tall, overnourished.
[2] Slightly undernourished.
[3] Tall.
[4] Somewhat thin.
[5] Tall, thin.
[6] Overnourished.
[7] Fairly well developed and nourished; slightly under par.
[8] Below par mentally.
[9] Very muscular.
[10] Stupid, overnourished.
[11] Tall, gawky, slightly undernourished.
[12] Overnourished; tall; puberty.
[13] Thin, slightly undernourished.
[14] Puberty (?).

TABLE 28.—*Minimum heat production of girls at different ages.*

[Children normal unless otherwise stated. The data indicated by asterisks (*) were not used on the general metabolism charts for girls (figs. 23 to 47, pages 135 to 175) or on the anthropometric charts (figs. 5, 6, 8, 12, 13, and 14, pages 43 to 68) but were used, along with the other data in this table, on the individual charts for these children (figs. 15 to 21, pages 114 to 130).]

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
[1] 2	10 days	3.73	53.0	[2]0.248	96	152	41	611
[1] 12	9 days	4.20	53.0	[2] .268	133	199	47	743
[1] 26	10 days	3.56	50.0	[2] .239	110	185	52	774
[1] 35	8 days	4.42	54.0	[2] .278	117	198	45	712
	1 mo. 1 wk.	5.07	58.5	[2] .304	134	223	44	734
	4 mos.	7.17	64.5	[2] .384	125	329	46	857
[1] 48	1 mo. 1 wk.	4.81	56.0	[2] .293	127	211	44	720
	2 mos. 3 wks.	5.54	61.0	[2] .323	139	388	70	1,201
[1] 49	11 days	2.68	48.5	[2] .199	116	139	52	698
109	12½ days	3.86	51.5	[2] .253	114	200	52	791
[1]110 [3](E.P.)	13 days	3.71	51.0	[2] .247	122	182	49	735
111	13 days	3.57	53.0	[2] .240	147	200	56	833
[4]113	3½ wks.	3.65	53.0	.249	141	173	47	695
	* 5 wks.	3.99	....	....	135	178	45	695
	* 1½ mos.	4.40	....	....	129	211	48	754
	1 mo. 3½ wks.	4.55	57.5	.278	134	207	45	745
	* 2½ mos.	4.88	....	....	119	217	44	728
	* 3 mos.	4.98	....	....	133	253	51	861
	4 mos.	5.54	63.0	.332	120	289	53	871
	* 4 mos. 3½ wks.	6.04	....	....	115	324	54	967
	5 mos. 3 wks.	6.49	66.5	.360	120	351	54	975
[5]116 [1](A.C.)	1½ mos.	2.99	....	[2] .214	126	163	55	759
[4]120 [1](B.D.)	2 mos.	4.90	58.0	[2] .297	122	274	57	927
122	2 mos. 1 wk.	5.15	58.5	.309	126	257	50	830
	* 3 mos.	5.62	....	....	135	299	53	911
	3 mos. 3½ wks.	6.03	62.5	.347	136	329	55	948
	1 yr. 6 mos.	10.1	78.5	.514	136	597	59	1,161
	* 1 yr. 6 mos. 3½ wks.	10.4	....	....	127	653	63	1,251
123	2 mos. 1 wk.	3.85	53.5	.244	129	235	61	963
	* 2½ mos.	4.37	....	....	131	251	57	923
	* 2 mos. 3½ wks.	4.44	....	....	129	280	63	1,098
	* 3 mos. 1 wk.	4.59	....	....	117	253	55	891
	6 mos. 1 wk.	6.09	63.0	.339	124	312	51	920
	* 6 mos. 3 wks.	6.06	....	....	114	325	54	962
	* 7 mos. 1 wk.	6.34	....	....	112	334	53	957
	8 mos. 3 wks.	6.75	65.0	.345	114	410	61	1,188
[6]127	2 mos. 3½ wks.	5.03	57.5	.291	115	255	51	876
	9½ mos.	8.11	67.0	.416	127	468	58	1,125

[1] Previously reported under initials given by Benedict and Talbot, Am. Journ. Diseases of Children, 1914, 8, p. 1. Data for girl designated by initials A. C. also reported by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914. Results for Nos. 2, 12, 26, 35, 48, and 49 reported under the same subject number by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915.

[2] Lissauer surface.

[3] Data as previously published incorrect.

[4] Certainly breast-fed. Probably many others were, but we are uncertain.

[5] Slightly undernourished.

[6] During second year had colds; continued to develop normally; breast-fed.

TABLE 28.—*Minimum heat-production of girls at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
127 (cont.)	*11 mos. 1½ wks.	7.98			111	453	57	1,051
	* 1 yr. 1½ wks.	8.28			115	500	61	1,131
	* 1 yr. 1 mo.	8.62			108	486	56	1,063
	* 1 yr. 2½ mos.	8.56			111	485	57	1,025
	1 yr. 4 mos.	9.06	73.0	0.482	114	549	61	1,138
	* 1 yr. 5 mos.	8.89			93	474	53	1,019
[1]131	3 mos.	4.34	55.5	.252	111	235	54	933
	* 3 mos. 1 wk.	4.64			122	279	60	1,045
	* 3 mos. 3 wks.	4.86			132	277	57	945
	4 mos. 1½ wks.	5.27	58.0	.310	118	311	59	1,003
	* 5 mos.	5.55			119	335	60	1,074
	* 6 mos. 1 wk.	5.76			120	314	55	928
	* 6 mos. 3½ wks.	5.87			119	340	58	1,005
	* 7 mos.	5.97			121	351	59	1,057
	7 mos. 2½ wks.	6.08	62.0	.333	124	353	58	1,057
[2]134 (L. R.B.)	4 mos.	5.99	64.0	[3] .340	106	331	55	973
[2]135 (M.C.)	4 mos.	6.17	63.0	[3] .347	103	333	54	967
[4]139	4½ mos.	5.19	63.0	.313	136	315	61	1,006
	* 5 mos.	5.27			121	280	53	864
	* 5 mos. 1 wk.	5.75			129	339	59	1,000
	* 6 mos.	5.99			119	314	52	952
	6 mos. 1 wk.	6.11	65.0	.351	124	325	53	926
	7 mos.	7.00	67.0	.383	135	406	58	1,060
	9 mos. 1 wk.	8.29	70.0	.420	129	419	51	997
	*10½ mos.	9.03			124	484	54	1,094
	1 yr. 2 mos. 3 wks.	9.67	76.0	.476	131	528	55	1,110
	* 1 yr. 4 mos.	9.81			113	491	50	989
	* 1 yr. 5 mos.	10.2			128	516	51	1,024
	* 1 yr. 6½ mos.	10.0			116	511	51	987
	1 yr. 8½ mos.	10.8	82.0	.538	109	531	50	986
	* 1 yr. 10½ mos.	11.1			99	525	47	948
	2 yrs. 2½ mos.	12.3	88.0	.590	110	590	48	1,000
	* 2 yrs. 5 mos.	12.8			101	549	43	895
	2 yrs. 6 mos. 3 wks.	13.6	92.5	.648	100	607	45	936
	* 2 yrs. 8 mos. 1½ wks.	13.4			93	579	44	930
	3 yrs. 2 mos. 3 wks.	14.0	96.0	.638	85	655	47	1,026
	* 3 yrs. 5 mos.	14.3			78	608	43	953
	* 3 yrs. 7 mos. 1 wk.	14.7			80	601	41	918
	* 3 yrs. 7 mos. 3 wks.	14.4			84	656	46	1,019
	3 yrs. 9 mos. 3 wks.	14.7	99.0	.666	85	624	43	937
140	4 mos. 3 wks.	6.02	60.0	.319	115	334	55	1,047
[5]144	5 mos.	7.91	62.0	.423	121	353	45	835
	9 mos.	10.6	67.5	.520	112	445	42	856
[5, 6]146	5 mos. 1 wk.	8.30	68.0	.425	119	360	43	847
	7 mos.	9.04	71.0	.426	119	419	46	984
[5]151	6 mos.	5.64	60.0	[3] .327	126	355	63	1,086
152	6 mos.	6.52	65.5	.360	117	357	55	997
160	7½ mos.	5.90	62.5	.342	123	417	71	1,219
	* 8 mos.	6.31			126	444	70	1,251

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[1] Slight facial eczema.

[2] Previously reported by Benedict and Talbot, Am. Journ. Diseases of Children, 1914, 8, p. 1. Data for girls designated by initials L. R. B., and M. C. also reported by Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914.

[3] Lissauer surface.

[4] At 3 yrs. had measles; no other illness except colds; breast-fed.

[5] Certainly breast-fed. Probably many others were, but we are uncertain.

[6] See table 26, p. 112, for data for No. 145.

TABLE 28.—*Minimum heat production of girls at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
160 (cont.)	10 mos.	7.05	65.5	0.375	126	492	70	1,312
	* 1 yr.	7.63	......	......	114	522	68	1,286
	1 yr. 3½ wks.	8.12	68.5	.407	113	522	64	1,283
	* 1 yr. 1½ mos.	8.11	......	......	117	537	66	1,313
	* 1 yr. 2 mos.	8.41	......	......	119	530	63	1,283
	* 1 yr. 2½ mos.	8.15	......	......	111	505	62	1,268
162	8 mos.	8.00	69.5	[1] .412	119	413	52	1,002
163	8 mos. 1 wk.	7.63	63.0	[1] .400	116	375	49	938
165	8 mos. 3 wks.	6.24	63.0	.370	93	338	54	914
[2]166	9 mos. 1 wk.	7.92	68.5	.408	116	505	64	1,238
	*10 mos. 3 wks.	7.98	......	......	119	482	60	1,100
	* 1 yr. 1½ wks.	8.62	......	......	126	557	65	1,255
	1 yr. 2½ mos.	9.21	74.5	.485	109	559	61	1,152
	* 1 yr. 4 mos.	9.45	......	......	105	570	60	1,171
	1 yr. 8 mos. 3½ wks.	11.1	80.0	.533	96	597	54	1,120
	* 1 yr. 10 mos.	11.4	......	......	105	625	55	1,143
	* 1 yr. 11 mos. 3 wks.	11.6	......	......	84	603	52	1,075
	* 2 yrs. 2 mos.	11.8	......	......	97	621	53	1,093
	2 yrs. 4 mos.	12.0	88.0	.581	91	655	55	1,128
	2 yrs. 9½ mos.	13.2	88.5	.599	95	692	53	1,155
	* 2 yrs. 11 mos.	13.3	......	......	......	710	53	1,239
	* 3 yrs. 1½ mos.	13.7	......	......	88	741	54	1,260
	* 3 yrs. 2 mos.	13.7	......	......	89	686	50	1,179
	3 yrs. 4½ mos.	14.0	92.5	.603	79	686	49	1,138
167	9 mos. 1 wk.	8.52	69.0	.458	126	522	61	1,140
[3]171	10 mos.	8.18	73.5	.415	123	502	61	1,210
	*10½ mos.	8.40	......	......	140	557	66	1,289
	* 1 yr. 1½ mos.	8.70	......	......	129	545	63	1,310
	1 yr. 2 mos. 1½ wks.	9.43	76.5	.465	141	606	64	1,303
	* 1 yr. 3½ mos.	9.50	......	......	124	613	65	1,330
	* 1 yr. 4 mos. 3½ wks.	9.75	......	......	110	612	63	1,330
	* 1 yr. 5 mos. 1 wk.	10.1	......	......	123	664	66	1,425
	1 yr. 9½ mos.	10.6	85.5	.494	107	643	61	1,302
	* 1 yr. 11 mos.	11.0	......	......	114	638	58	1,236
	2 yrs. 3 mos. 1 wk.	12.2	89.5	.579	109	735	60	1,269
	* 2 yrs. 4 mos. 1 wk.	12.3	......	......	102	649	53	1,106
	* 2 yrs. 5 mos.	12.1	......	......	99	666	55	1,164
	3 yrs. 3 mos. 1 wk.	14.2	100.0	.624	98	657	46	1,053
	4 yrs. 2 mos. 1 wk.	16.5	104.5	.681	85	718	44	1,054
	* 4 yrs. 3 mos. 2 wks.	16.2	......	......	89	.713	44	1,059
[4]172	11½ mos.	8.80	74.5	.456	116	568	65	1,246
	* 1 yr. 1½ wks.	9.30	......	......	121	608	65	1,277
	1 yr. 1 mo. 1½ wks.	9.84	77.0	.508	122	686	70	1,350
	* 1 yr. 2 mos. 1 wk.	10.0	......	......	123	677	68	1,317
	* 1 yr. 3 mos.	10.2	......	......	116	697	68	1,377
	* 1 yr. 4 mos.	10.4	......	......	111	647	62	1,242
	1 yr. 5½ mos.	11.1	80.0	.551	116	712	64	1,292
[5]173	11½ mos.	9.22	72.0	.461	126	600	65	1,300
	* 1 yr. 1 mo.	9.46	......	......	113	573	61	1,170
	* 1 yr. 2 mos.	9.98	......	......	119	552	56	1,131

[1] Lissauer surface.

[2] At 1 yr. 4 mos. had measles; no other illness except colds; breast-fed.

[3] At 1 yr. 1 mo. had chicken pox; no other illness except colds; developed normally; breast-fed.

[4] Adenoids removed when 1 yr. old.

[5] During second year had colds.

TABLE 28.—*Minimum heat-production of girls at different ages*—Continued.

Subject No.	Age.	Body-weight (without clothing).	Height.	Body-surface (Du Bois linear formula).	Average pulse-rate.	Heat (computed) per 24 hours.		
						Total.	Per kilo.	Per sq. m.
		kilos.	*cm.*	*sq. m.*		*cals.*	*cals.*	*cals.*
173	* 1 yr. 3 mos.	9.81	......	....	109	554	56	1,140
(cont.)	1 yr. 5 mos.	10.6	78.0	0.522	109	614	58	1,176
	* 1 yr. 6½ mos.	11.0	......	....	97	622	57	1,154
174	2 yrs. 1 mo.	11.0	79.0	.543	102	604	55	1,112
178	2 yrs. 11 mos.	12.4	92.0	.608	88	543	44	894
[1]179	3 yrs. 8 mos.	14.5	98.5	.654	76	560	39	856
180	3 yrs. 10 mos. 3 wks.	15.0	93.5	.691	92	640	43	926
181	3 yrs. 11 mos.	16.4	98.5	.701	88	771	47	1,100
[3]183	4 yrs. 3 mos. 3 wks.	15.7	97.5	.654	77	673	43	1,028
184	4 yrs. 4 mos. 1 wk.	16.2	103.0	.716	92	715	44	999
188	5 yrs. 1½ mos.	16.6	103.5	.728	110	782	47	1,075
[2]189	5 yrs. 3 mos. 1 wk.	22.7	116.0	.872	79	829	37	951
190	5 yrs. 3½ mos.	15.2	103.5	.691	81	637	42	922
[3]191	5 yrs. 5½ mos.	18.7	107.5	.748	85	790	42	1,056
[4]195	6 yrs. 3 wks.	16.4	99.5	.665	91	792	49	1,191
[5]196	6 yrs. 5½ mos.	19.7	118.0	.816	....	747	38	915
198	6 yrs. 9 mos.	26.4	124.5	.991	73	918	35	926
[2]203	7 yrs. 1 mo. 2 wks.	23.1	119.0	.881	74	849	37	964
[6]206	7 yrs. 4 mos.	19.2	113.0	.787	74	752	39	956
	8 yrs. 2 mos.	20.8	116.0	.837	71	863	42	1,031
210	8 yrs. 2 wks.	23.9	122.5	.930	86	894	38	961
	8 yrs. 5 mos. 3 wks.	26.0	123.5	.988	79	1,002	39	1,014
[2]214	8 yrs. 2 mos.	26.0	126.0	.970	65	930	36	959
219	8 yrs. 11 mos. 1 wk.	23.7	125.0	.922	81	880	37	954
[3]220	9 yrs. ½ mo.	22.5	122.0	.938	97	977	43	1,042
221	9 yrs. 3½ wks.	26.1	122.0	1.021	76	902	35	883
225	9 yrs. 5 mos. 1 wk.	24.0	120.5	.906	79	924	38	1,020
[7]227	9 yrs. 9 mos.	24.8	125.5	.935	82	919	38	983
[7]230	10 yrs. 3 mos.	27.9	133.0	1.058	77	999	36	944
[8]233	10 yrs. 5 mos. 2½ wks.	29.8	131.0	1.062	68	896	30	844
[3]234	10 yrs. 5 mos. 3½ wks.	28.2	133.0	1.033	74	923	33	894
238	10 yrs. 9 mos. 3½ wks.	28.0	135.5	1.047	90	944	34	902
[9]239	11 yrs.	27.4	133.5	1.083	76	984	36	909
	12 yrs. 1 mo.	39.2	147.5	1.272	72	1,500	38	1,179
[10]248	11 yrs. 10 mos. 3 wks.	28.8	129.0	1.035	75	1,062	37	1,026
[11]251	12 yrs. 2 mos.	30.9	138.5	1.100	78	1,012	33	920
257	13 yrs. 3 mos. 3 wks.	37.1	140.5	1.222	74	1,318	36	1,079

[1] Flesh slightly flabby.
[2] Overnourished.
[3] Slightly undernourished.
[4] Well developed and nourished, with chronic endocarditis.
[5] Tall, thin.
[6] Weak ankles, the result of old infantile paralysis.
[7] Thin.
[8] Overnourished; puberty.
[9] Puberty established at 12 yrs. 1 mo.
[10] Fat, healthy, rosy-cheeked.
[11] Puberty beginning.

ments are concerned, it is of interest to consider them somewhat in detail. It is important to note that the scale upon which the charts for these children are drawn is somewhat different from that used for No. 145. (Compare figs. 15 and 16.)

The individual points in these charts are so numerous as to produce curves that are by no means smoothed. The general trend of the body-weight curves of both Nos. 139 and 171 is that of a progressive increase, as is common with a normal infant. The total calories per 24 hours fully substantiate the general line noted for No. 145, namely, a rather rapid rise until about 2 years of age, after which there is a tendency for a clearly defined rise, although at a somewhat slower rate.

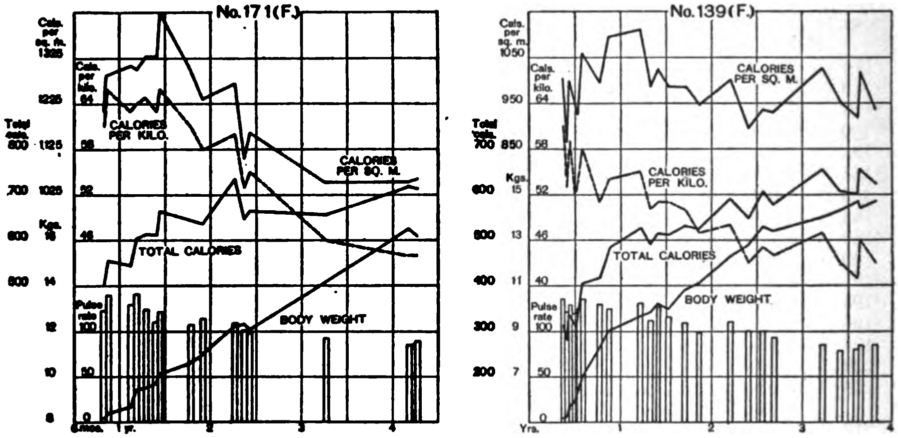

Fig. 16.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 171 and 139).

While emphasis must again be laid upon the inherent errors in the measurement of individual periods, an attempt has been made to select only such points as were fully substantiated by the results for another period on the same day or on the day immediately preceding or following. Consequently in these charts the individual points can for the most part be considered as truly representative of the metabolic plane at the time of measurement. A high point in the total calories is never based upon a single experimental period. This is emphasized to bring out the fact that with children the regularity in the heat production from day to day is not perfect on any basis, and rather considerable fluctuations may normally be expected to obtain, even in periods with complete muscular repose and (though not with a true post-absorptive condition) at least with the influence of food very considerably minimized.

The calories per kilogram of body-weight for these two children (Nos. 139 and 171) show a fall (as the weight and age increase) quite in conformity with that noted with No. 145. The calories per square meter of body-surface for both the children show a maximum occurring from about 1 year 4 months to 1½ years, and a tendency towards a fall thereafter. With No. 171, for example, the maximum value is 1,425 calories per square meter of body-surface and the minimum 1,053 calories. With No. 139 a greater uniformity is observed, the range being from 1,110 to 864 calories. The curve for No. 171 is sharply distinguished from the curve for No. 145, in that it shows an early

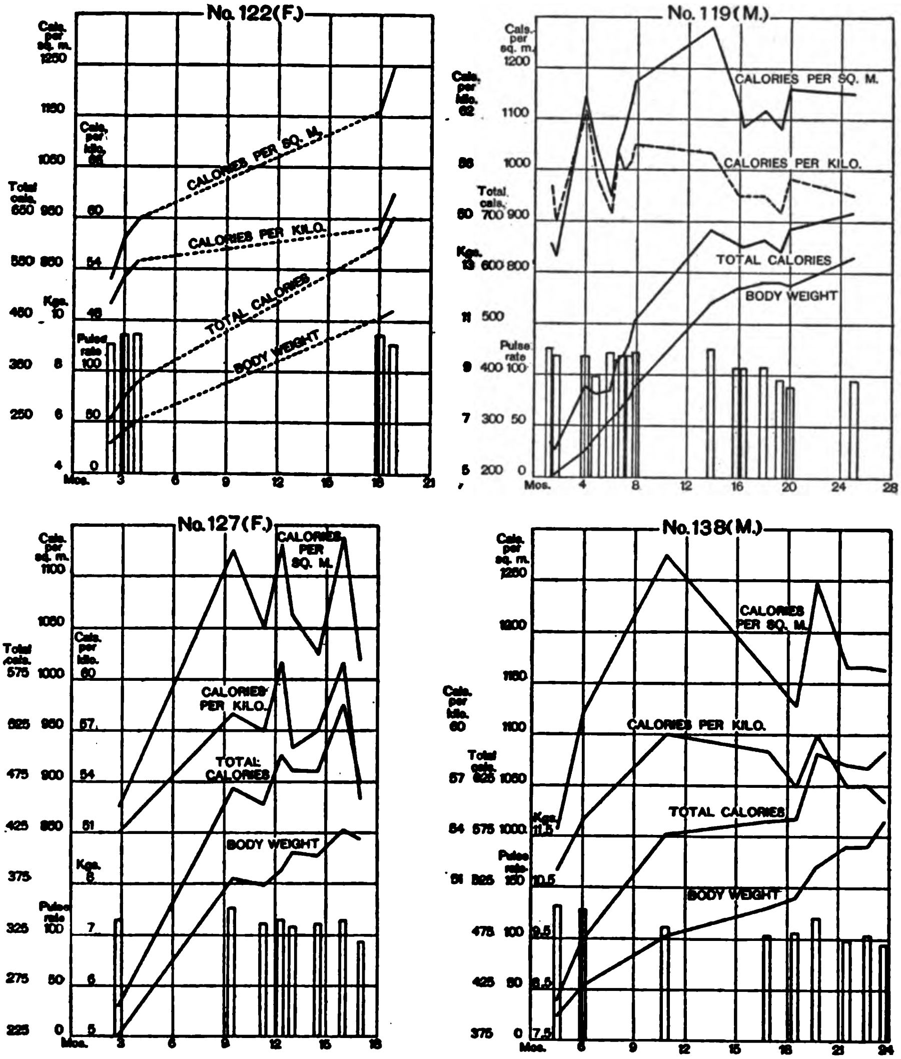

FIG. 17.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 119, 122, 127, and 138).

period of low values for the calories per square meter of body-surface which does not appear in the chart for No. 145. The pulse-rate, high at about 1 year, gradually falls off with both Nos. 139 and 171, and fully confirms the observations drawn from the chart for No. 145.

Intimate analysis of the other 20 charts is hardly necessary. Since, however, the charts thus far analyzed show no special values in the earlier months of life, at least the physiological relationships at this period should be pointed out. Attention is called to the charts for those children with whom observations were made at an early age, such as Nos. 113, 115, and 119. (See figures 17, 18, and 19, pages 125 to 127.) In these charts the weight-curve and total calories present the usual features, namely, progressively increasing weight and progressively increasing total calories. The increase in the values for the calories per kilogram of body-weight and per square

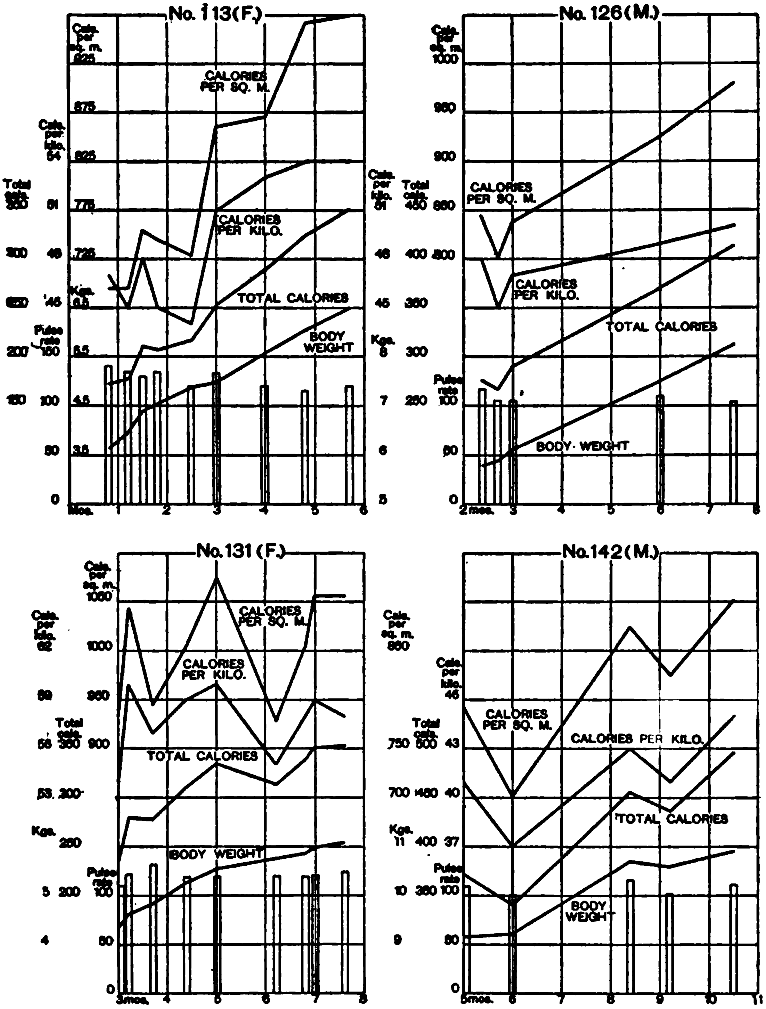

FIG. 18.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 113, 126, 131, and 142).

meter of body-surface with an increase in age is worthy of consideration. With No. 115, for example, the heat per kilogram of body-weight rises from 49 calories at the age of 1 month to 61 calories at the age of 5 months, the whole trend of the curve being upwards. When measured on the basis of body-surface, the heat is as low as 765 calories at 1 month and rises to 1,061 calories at the end of 5 months.

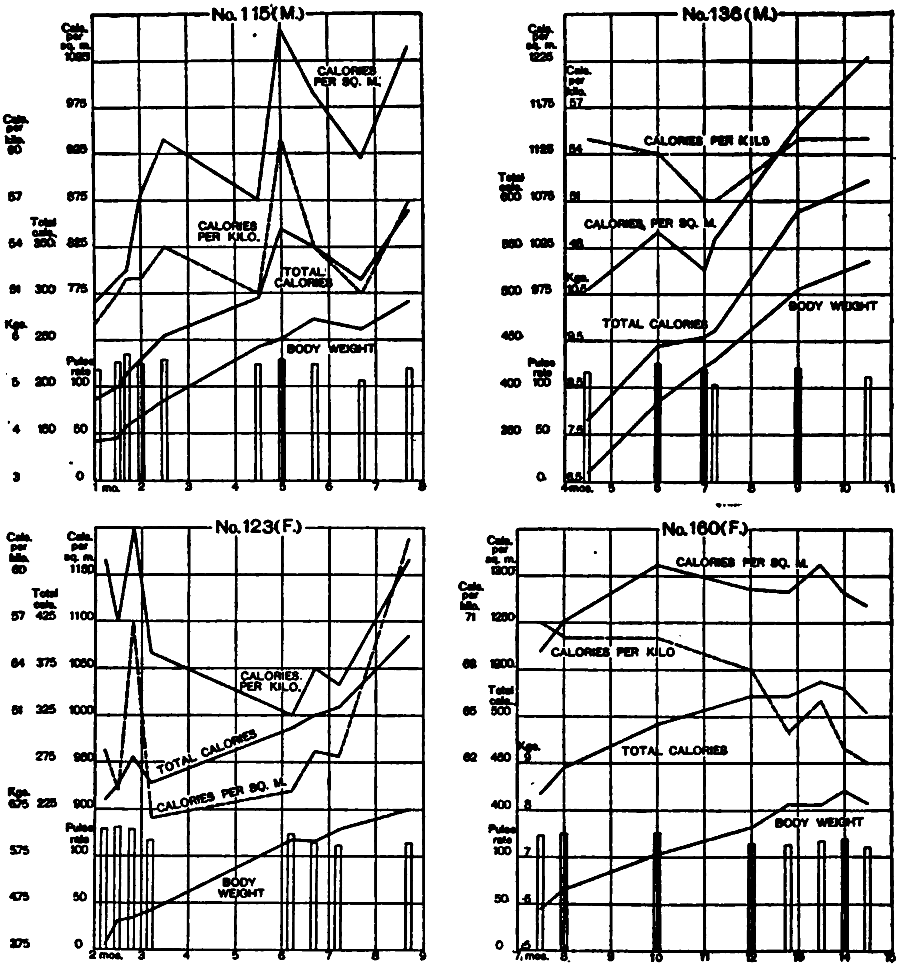

FIG. 19.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 115, 123, 136, and 160).

An examination of other charts, such as that for No. 113 (fig. 18) and those for the younger children, shows similar general trends, namely, low heat values on the bases of body-weight and body-surface, with a gradual increase as the age advances from 7 months to 1 year. Of special significance is the fact that these wide variations in the heat production per square meter of body-surface are found with the very young children. This is in conformity with variations observed by us in our studies of new-born children, in which it was noted that the heat production per square meter of body-surface decreased at times to 459 calories.[1] When our early analysis of the figures for the heat production of new-borns was made, our use of the Lissauer formula for computing the body-surface was obviously open to some criticism. Subsequently, as shown in another section of this report, it was found that the Lissauer formula gives measurements agreeing admirably with those of Du Bois for children weighing up to 10 kg. During this early period from birth to 6 or 7 months, the body-weights are for the most part under 10 kg. Hence we have every reason to believe that our estimates of the heat production per square meter of body-surface are as close as can possibly be made in the present state of physiological science.

The pronounced individuality of the children studied in these longer series, as evidenced by the fluctuations in the smoothed curve, are altogether too great to permit any consideration of a normally progressing, increasing metabolism. It is thus difficult to draw general deductions from this extensive series of charts. Those permissible are, first, the normally increasing body-weight common to all normal children; second, the reasonably close paralleling of the total calories with the body-weight curve, namely, an increase in total calories with an increase in body-weight; third, the low calories found on the bases of body-weight and body-surface shortly after birth, increasing to a maximum not far from one to two years of age, with a tendency for a definite decrease thereafter. Finally, the pulse-rate is noticeably highest in the period from birth to 1 or 1½ years, with a tendency to fall thereafter. No perfect picture of the general physiological trend can possibly be made from a visualization of these several groups of data for the individual children. Final recourse must therefore be made to our main study of a large number of children of different ages, weights, lengths, and body-surfaces, so as to plot all values on large charts and thus study the general trend.

METABOLISM DURING GROWTH AS SHOWN BY GROUPS OF INDIVIDUAL DATA.

In the preceding section it has been made clear that, with a given individual, there is no smoothed curve for metabolism like that, for example, obtained for body-weight with a fasting dog[2] or, indeed, with a fasting man. Daily basal metabolism is subject to very considerable fluctuations, which are nowhere more strikingly shown than in the charts for individual children in figures 15 to 21. Plotting all the points on the charts in one scatter-diagram and sketching a curve indicating the general trend would obviously smooth the individual differences, not only for the same child from day to day, but between the children studied. This we have not done, but recognizing the value of grouping all observations in a series of charts so as to present the general trend of metabolism of a relatively large number of children, and thus visualize the influence of sex, age, weight, and surface on metabolism, we have gathered together not only the data from the 23 individual charts in figures 15 to 21, but also the isolated observations on a large number of children, mostly of the higher ages, and plotted these values in several scatter-diagrams. In these diagrams the caloric output is referred respectively to age, weight, and surface area in a number of ways.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, pp. 96 and 100.

[2] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, pp. 77 and 75.

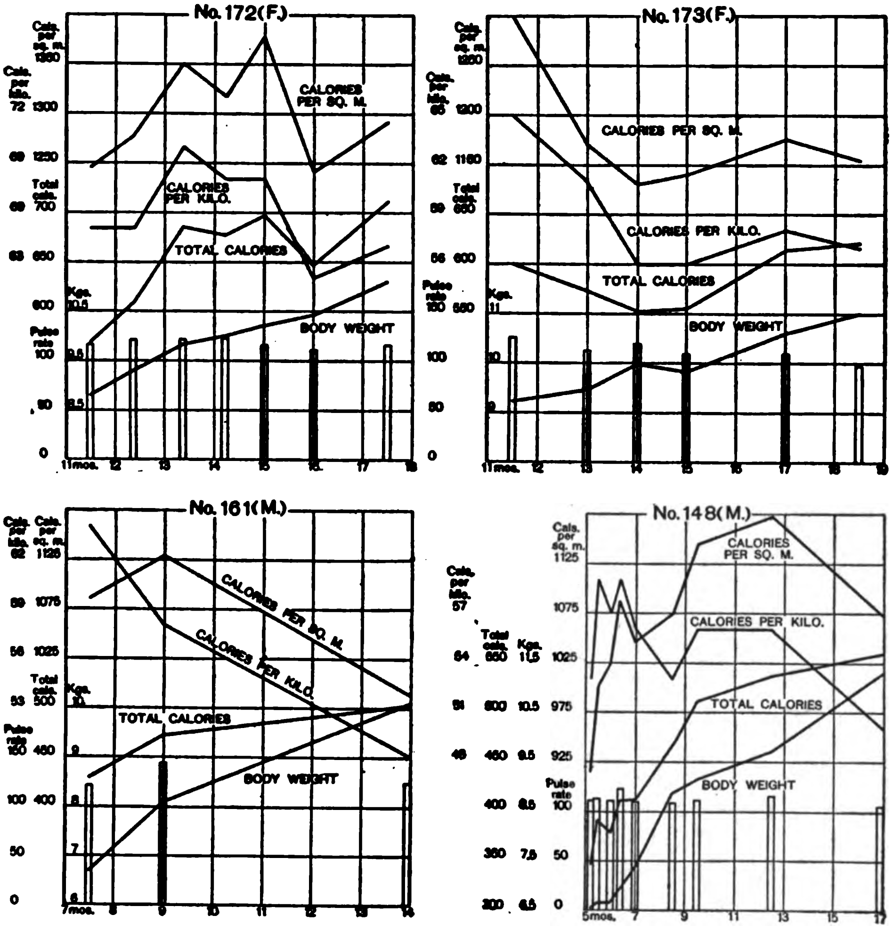

FIG. 20.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 148, 161, 172, and 173).

In studying these diagrams, we may ask: Is the metabolism of a child of given height, age, and weight the same as that of another child of the same height, age, and weight? Are there individual differences in metabolism? What is the influence *per se* of height, weight, age, and area on metabolism? What are the sex differences?

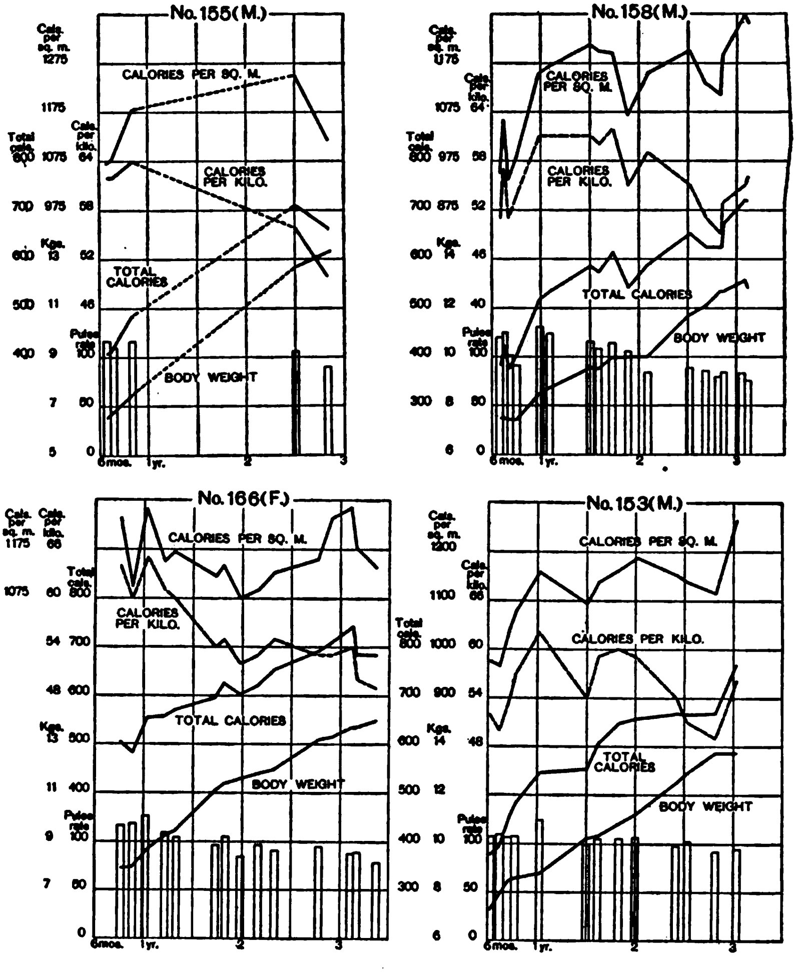

FIG. 21.—Body-weight, pulse-rate, and basal heat production per 24 hours (Nos. 153, 155, 158, and 166).

All these problems may only adequately be studied by an intelligent comparison of extensive series of metabolism measurements. The individual curves show the general relationships between growth and metabolism, but they give information only obscurely and indirectly which may be used for a comparison of one child with another on the basis of age, height, and weight, and throw no light on sex differences.

When children are considered as a class, the gross differences in age, weight, and stature make it extremely difficult to find two children of exactly the same age, weight, and height. Certainly any series of metabolism measurements would have to be greatly extended and include a large number of subjects to secure two individuals who were strictly comparable in these respects. The time and expense required for such measurements would prohibit any attempt to make sufficient studies with a large number of individuals for the establishment of probable standards for the many combinations of the four variables—sex, age, weight, and height. This likewise holds true for adults; and yet it is very important, physiologically at least, to have some conception of differences in metabolism with different individuals.

METHOD OF GROUPING DATA.

Any plan for the comparative study of the metabolism of children involves one or more forms of classification. Following the custom of physiologists, we have charted the values first on the basis of age, then of body-weight, and finally of body-surface. Since with adults it has been clearly shown that there is a sexual differentiation, it seems desirable to consider the boys and girls separately, even though a critical analysis of the data for new-born babies[1] showed no sexual differentiation during the first week of life. A comparison of the various individual charts (figs. 15 to 21), in which the sex was indicated, or even a superficial inspection of these general charts (figs. 22 to 47) for boys and girls, gives but little, if any, suggestion of a sexual differentiation. Such grouping is of value, however, for use in a more thorough comparison of all the data in several large plots (see figs. 48 to 51, pages 179 to 181), by which the differences in the results due to sex may be discerned.

As previously stated on page 101, during the period of growth represented by the observations in this study there are such rapid changes in weight and age that it has been considered perfectly legitimate, when appreciable variations in these two factors occur, to regard the child as a different individual and to plot the values accordingly in these group charts. In determining the points on the charts in figures 22 to 47, each child was considered a new individual after (1) an increase in weight of 1 kg. for children weighing less than 10 kg.; (2) an increase in weight of 10 per cent for children over 10 kg.; (3) an increase in age of 6 months. Change in height *per se* was not considered. While the classification for weight and age was not strictly adhered to, there was but little deviation from the rule. So far as possible, breaks in the continuity of evidence were avoided, and if an observation was made at the end of a series, it was not necessarily excluded, even if the full change in weight or age had not been reached. It frequently happened that the full change in weight occurred considerably inside of 6 months, and there were also instances when a change in age of 6 months was not accompanied by a full change in weight. By this method, certain children, notably No. 145, appear a number of times upon the charts or scatter-diagrams. For instance, in figure 22, the actual number of boys represented is 88, while the number of points plotted is 129. These latter in reality correspond to an equal number of children, since the values found on the same boy are characterized by an appreciable difference in age or weight.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915; Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919.

A biometrical analysis of the data in this series of observations has not been attempted, but on each of the group charts an effort has been made to indicate the apparent general trend of the metabolism on the basis selected for comparison by laying on arbitrarily a smoothed curve. It must be emphasized here that these curves do not represent mathematically determined trends, but are simply sketched from observation of the general distribution of the points. The curves were prepared in the manner previously referred to (see page 37), *i. e.*, five members of the Laboratory staff, accustomed to plots and curves, each drew on a separate sheet of tracing-paper a curve which appeared to him as the most probable. These curves were then combined and the line reproduced on the respective charts represents the average of these five plots. While this procedure is admittedly unmathematical, it serves at least to indicate the general trend of the metabolism.

All of the precautions cited in our discussion of normality entered into the selection of the individuals and points plotted in these group charts. In a preliminary communication published elsewhere[1] regarding this study of children during the period of growth, a series of charts was given similar to those in figures 22, 23, 26, 27, 30, 31, 35, 36, 42, 43, 45, and 47. The earlier charts differed only in the number of points included, which was somewhat greater than in the present series, as a more rigid exclusion of material was made previous to the final printing here. A comparison of the two sets of smoothed curves brings out the interesting fact that those obtained in the preliminary charting of the values, which were prepared in much the same manner as the later curves, do not differ by a measurable amount from the curves subsequently sketched for the final series. In other words, the eliminations made exclusively on the basis of a more critical examination of the protocols and histories for evidence of the normality of the children have resulted in the removal of an approximately equal number of points above and below the line, so that the position of the line itself is not materially changed. This fact is of considerable practical as well as physiological interest as indicating that, in an attempt to secure a more nearly perfect measure of normality, the evidence as to the general trend of the metabolism has not been affected. One can thus, even at this point, make the deduction that with the general population as studied, the deviations above or below a central tendency are such as to balance, and that the influence upon metabolism of slight deviations from physical normality is negligible.

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[1] Benedict, Boston Med. and Surg. Journ., 1919, 181, p. 107.

General Trend of Metabolism with Increasing Age.

In this series of group charts, the first comparisons have been made for the total metabolism as referred to age.

TOTAL CALORIES PER 24 HOURS REFERRED TO AGE (BOYS).

The total calories per 24 hours referred to age for the boys have been charted in figure 22. An inspection of this chart shows a rapid rise in the total metabolism during the first year of life and from the first to the thirteenth year a somewhat slower but steady increase. This general trend seems to be continued beyond the thirteenth year; but only three points are available for comparison beyond this age.

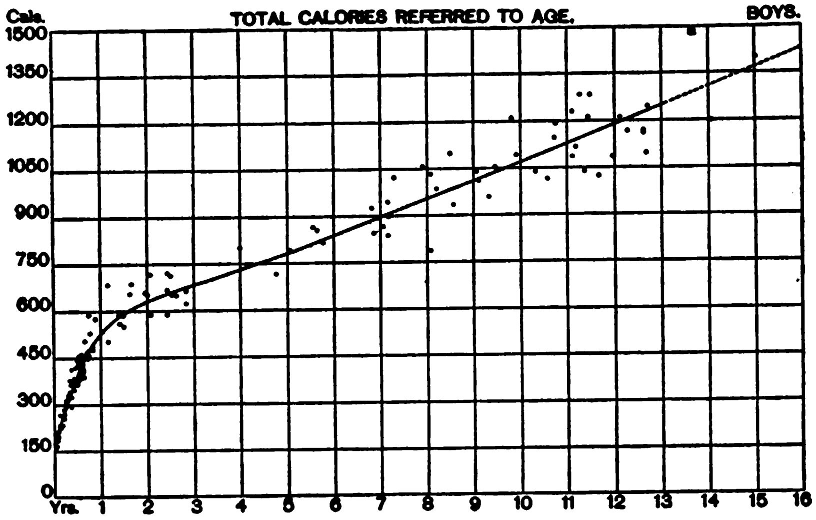

Fig. 22.—Basal heat production of boys per 24 hours referred to age. Point inclosed in square signifies puberty established.

The interpretation of the sketched curve is beset with a number of difficulties. In the first place, the arbitrary laying-down of a smoothed curve on a plot of this character gives too much weight to the possibility of a constancy in metabolism. That this constancy is not actually present is clearly shown by the deviations from the line all along the curve, particularly after 8 months of age. It would appear as if the metabolism during the first 8 months followed with singular accuracy the direction of the curve. At this point we find the second great difficulty in the proper interpretation of this type of curve, namely, the percentage deviations. For example, at the age of 11 years, a deviation of half a square either side of the curve corresponds to 75 calories, or, with a basal metabolism of 1,125 calories, a difference of not far from 7 per cent. At the age of 6 months a like deviation has exactly the same numerical value as at 11 years, *i. e.*, 75 calories, but on the percentage basis this variation at 6 months represents an error of about 20 per cent, since the basal metabolism is considerably less. Hence the seemingly close grouping of points about the general line in the earlier years is only apparent and does not necessarily indicate a greater uniformity in the metabolism. This particular phase must be borne in mind for all of the charts, since it is the common custom of physiologists to consider deviations in metabolism either side of a so-called normal on the percentage basis and these charts can not be so used. The chief usefulness of the chart in figure 22 is to indicate the tendency for the metabolism to increase rapidly during the first year of life and to rise steadily, though not so rapidly, during the remainder of youth.

It should be pointed out at this juncture that two of the three values beyond the age of 13 years lie above the projected line. With one of these boys (13 years and 8 months old) signs of puberty were very clearly present.[1] The other two showed no signs of puberty. These facts are emphasized, since subsequent discussion of the metabolism as influenced by puberty is necessary, owing to the great stress laid upon this point throughout the literature, beginning with the earlier studies of Andral and Gavarret. Our data do not permit the discussion of the influence of puberty upon the metabolism, as the observations did not extend to this point, but the accumulation of experimental material along this line is now in progress at the Nutrition Laboratory.

Neither is this the time to consider the possibility of predicting the metabolism of various ages by referring to the general curve or central tendency for the basal metabolism, except as we may lay down the general principle that as the age increases the metabolism increases, and with a reasonable degree of uniformity.

TOTAL CALORIES PER 24 HOURS REFERRED TO AGE (GIRLS).

It is the general opinion that boys as a rule are much more active physically than girls, are less controllable, and can less easily acquire a condition of repose. This has a bearing upon any analysis of the metabolism figures for boys and girls as to sexual differentiation. By design, our observations included a relatively large number of girls, and therefore provide sufficient points for special chart treatment. The total metabolism of the girls referred to age is depicted in figure 23. The total number of points is essentially the same as for boys, and for the most part end prior to puberty. Beyond the age of 11 years, the values are much scattered and but four points are available. One of these points, that for a girl 12 years and 1 month old, is the same child as that indicated by the point for 11 years. At both ages the points are specially designated for convenience in comparison of the metabolism before and after the establishment of puberty. This difference in metabolism is discussed in a later section. (See page 183.)

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[1] The values for children showing evidences of puberty are represented on the charts by enclosing the point in a square. See discussion of these values on page 183.

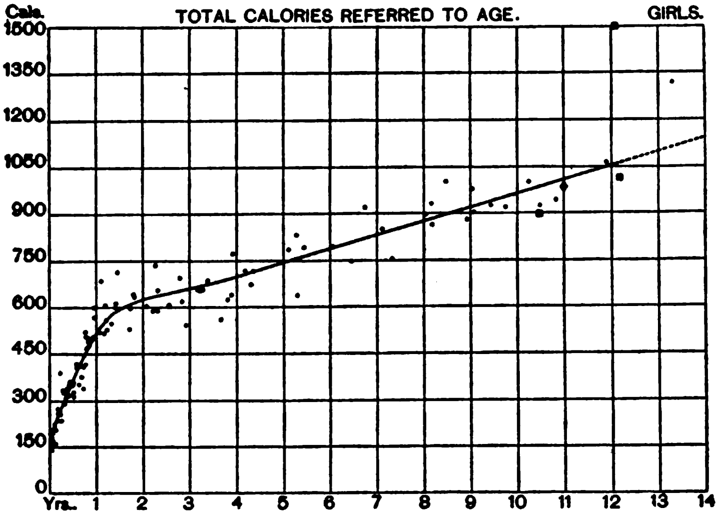

Fig. 23.—Basal heat production of girls per 24 hours referred to age.
Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 12 years 1 month (puberty).

The sharp rise in the total metabolism in the first year of growth is shown in figure 23, as well as the general steady increase thereafter. The smoothed curve does not fit the points quite so satisfactorily as with the boys, since between the ages of 2 and 4 years there is clearly an alteration in the general trend, which is not noticeable with the boys. This requires a slight alteration in the direction of the line, but again it must be remembered that this line is purely hypothetical and may not be looked upon as indicating a definite regularity in metabolism, but only the general trend.

While only a superficial inspection can be given these charts for boys and girls, there seems to be a general tendency for the points to group themselves somewhat more closely about the general line with the boys than with the girls.

TOTAL METABOLISM OF CHILDREN REFERRED TO AGE (EARLIER INVESTIGATORS).

Since our study was made primarily to secure the metabolism under conditions giving the basal metabolism, *i. e.*, with the values unaffected by muscular activity and with but little and preferably no influence of food, it is important in comparing our results with those of earlier writers to include of the latter only those obtained under conditions approximating complete muscular repose. As shown in a consideration of the previous literature on this subject (pages 4 to 21), relatively few of the earlier values meet these conditions. For example, all the studies of Andral and Gavarret[1] were made with the children in the sitting position and the data obtained (see table 1, page 5) indicate a total metabolism per 24 hours much higher at the low ages than that found by us with either boys or girls. Such values of the earlier studies as are suitable for comparison have, however, been charted, together with the lines showing the general trends noted on our several charts.

The values for the boy and girl studied by Scharling[2] can advantageously be plotted, but the data for Forster's[3] children are averaged in such a way that it would be difficult to apply them on our charts. For example, he finds no material change in the carbon-dioxide production per 10 kg. with children throughout the period from 3 to 7 years of age, namely, 11.7 grams per 10 kg. per hour, or approximately 3.50 calories per kilogram per hour. Since no data as to the body-weight are given, it is impossible to plot his values on our charts, but those given for children from 3 to 7 years of age correspond to about 84 calories per kilogram per 24 hours, which is far in excess of values noted by us for any age. This high metabolism is made the subject of special discussion by Forster.

Speck's experiments,[4] which were made after the ingestion of food and with the child in the sitting or standing position, are also unsuitable for comparison with our data.

The results of Sondén and Tigerstedt's extensive series[5] for the most part can not be employed here, with the exception of the data obtained with two subjects asleep. Thus with one boy, 11 years 2 months old, and with a body-weight of 32 kg., the total heat was 1,237 calories per 24 hours, a value quite in conformity with some points noted by us. Another boy, 12 years of age, showed a somewhat higher heat output of 1,373 calories.

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[1] Andral and Gavarret, Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 129.

[2] Scharling, Ann. d. Chem. u. Pharm., 1843, 45, p. 214; reprinted in detail in Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 478.

[3] Forster, Amtl. Ber. d. 50 Versamml. deutsch. Naturf. u. Aerzte in München, 1877, p. 355; also v. Ziemssen's Handbuch der Hygiene, Leipsic, 1882, 1, p. 76. See, also, Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., 1899, Suppbd., p. 356.

[4] Speck, Physiologie des menschlichen Athmens, Leipsic, 1892, p. 217.

[5] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 1.

Rubner's classic experiments[1] unfortunately give no values which are suitable for comparison. The data of Magnus-Levy and Falk[2] for both boys and girls are especially suitable for use and have all been plotted on our charts. Owing to the extensive criticisms applicable to the work of von Willebrand,[3] we do not feel justified in employing any of his data for comparison purposes, although it is not improbable that certain scattered minimum values are normal. Olin's experiments[4] were likewise made under conditions that can not be looked upon as basal. Finally, values have been plotted for such of Murlin and Hoobler's[5] children as were strictly normal, and also the results obtained in the extended series of Du Bois[6] and his collaborators are plotted, although criticism has been raised of these latter as to the selection of minimum periods and the degree of muscular repose.

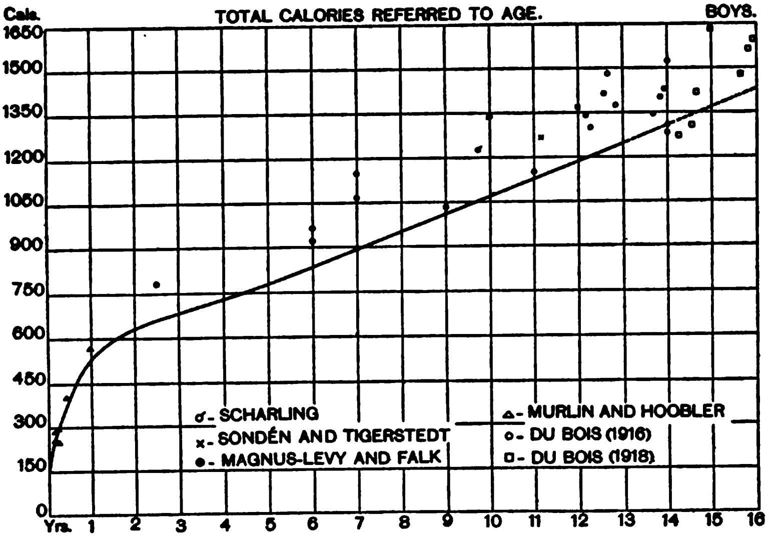

FIG. 24.—Basal heat production of boys per 24 hours referred to age (earlier investigators).

Comparison for boys.—The points representing the children studied by us are so numerous as to make it unwise to reproduce them on the same chart with those obtained by former investigators. Consequently, points for the results found by the earlier workers have been plotted and the line corresponding to the general trend shown in our studies as laid on the chart in figure 22 has been placed for comparison on the chart in figure 24, which gives the results for boys. The striking feature of this chart is that above the age of 1 year practically all of the earlier observations lie above the line, the exceptions being two boys studied by Du Bois and one boy observed by Magnus-Levy and Falk. Aside from these three cases, the general trend of metabolism in practically all the other studies was at a noticeably higher level than that found by us. A number of Magnus-Levy's observations lie very close to our line; this would seem to confute the general conception suggested by Harris and Benedict[1] that the observations of Magnus-Levy possibly indicate a racial difference in metabolism. From a critical analysis of the earlier researches it would seem probable that the conditions for basal metabolism, particularly with respect to muscular activity, were by no means so rigidly adhered to in the earlier observations as in ours, and we believe that no evidence exists thus far to suggest that the differences in the results may not be entirely explained by a difference in activity, without the necessity of implying a racial difference in the metabolic level. Certainly, with Du Bois's data, we are dealing with American material.

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[1] Rubner, Beiträge zur Ernährung im Knabenalter, Berlin, 1902.

[2] Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., 1899, Suppbd., p. 314.

[3] von Willebrand, Finska Läkaresällskapets Handlingar, 1907, 49, p. 417.

[4] Olin, Finska Läkaresällskapets Handlingar, 1915, 57, p. 1434; also Skand. Archiv f. Physiol., 1915, 34, p. 414.

[5] Murlin and Hoobler, Am. Journ. Diseases of Children, 1915, 9, p. 81.

[6] Du Bois, Arch. Internal Med., 1916, 17, p. 887. Olmstead, Barr and Du Bois, Arch. Internal Med., 1918, 21, p. 621.

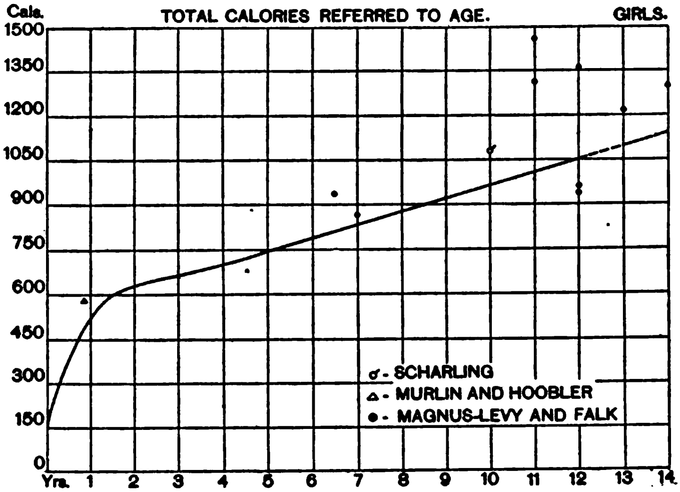

FIG. 25.—Basal heat production of girls per 24 hours referred to age (earlier investigators).

Comparison for girls.—While very few measurements of the metabolism of girls have been made, for the sake of consistency we have plotted in figure 25 the few observations we have been able to find in the literature and have laid our curve for girls upon the same chart. We find here two values of Magnus-Levy below our line; the other values lie above it. The two low values of Magnus-Levy for 12-year-old girls are of special interest, since, in the analysis of Magnus-Levy's data made by Harris and Benedict,[2] these two girls had a predicted metabolism calculated with the American normal (multiple prediction) formula for man that agrees remarkably well with that found, while all the other values are much higher. With girls, therefore, as with boys, the results of the earlier observations tend, in general, to have a higher level of basal metabolism than was found in our series.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 235.
[2] *Ibid.*, p. 236.

GENERAL CONCLUSIONS AS TO TOTAL METABOLISM AND AGE IN CHILDREN.

Our observations indicate a continually increasing metabolism from birth to 13 years of age with both boys and girls. A slight deviation in the general trend, as shown by the hypothetical smoothed curves laid on these charts, suggests that the trend for girls is slightly different from that of boys, especially about the age of 2 to 4 years. No other sexual differentiation can at this point of the analysis be observed.

Reference to all the available earlier observations suitable for comparison as basal measurements shows that for boys, save in rare instances, the observations always lie considerably above our line representing the general trend. The scattered observations with girls indicate substantially the same situation. From a careful analysis of all the earlier experiments, we believe that the results of our observations more nearly approach the true basal values than those of the previous investigations; hence, in lieu of further data, they must be looked upon as the closest estimates of the true basal metabolism of youth that have thus far been obtained.

Total Metabolism with Increasing Body-Weight.

While physiological observations with children are commonly referred to age, it is particularly unfortunate that the total metabolism should be thus referred, for experience with adults has shown us that a number of physiological factors play an important rôle in the total metabolism, among these being body-weight, stature, and age. Of these, body-weight has by far the greatest influence, much greater than that of age; consequently we should more properly refer the total number of calories per day to the body-weight rather than to the age of the child. In general, the larger the child is, one would *a priori* expect a greater metabolism. Furthermore, since we have found that the metabolism increases with age, and since age and body-weight, especially during the period of growth, go more or less hand in hand, we should expect changes in metabolism to be in reasonable conformity with changes in weight. Our curves representing the relationship between total calories and age may simply be an expression of the fact that as children grow older they likewise grow heavier, and the larger organism has a larger heat production. Physiologically, therefore, the better method of comparison is on the basis of weight rather than of age.

TOTAL CALORIES PER 24 HOURS REFERRED TO WEIGHT (BOYS).

In figure 26 we have plotted for boys the total calories per 24 hours referred to body-weight. The general sweep of the curve and the dispersion of the points about a central sketched line is not unlike that for boys for the total calories referred to age. (See fig. 22, page 133.) In fact, a superficial inspection would imply that of the two charts the points are even more closely grouped about the central line in figure 26. In such comparison it should be noted that the scales in the two charts are somewhat different, since each vertical division in figure 22 corresponds to 150 calories, while in figure 26 it corresponds to but 100 calories.

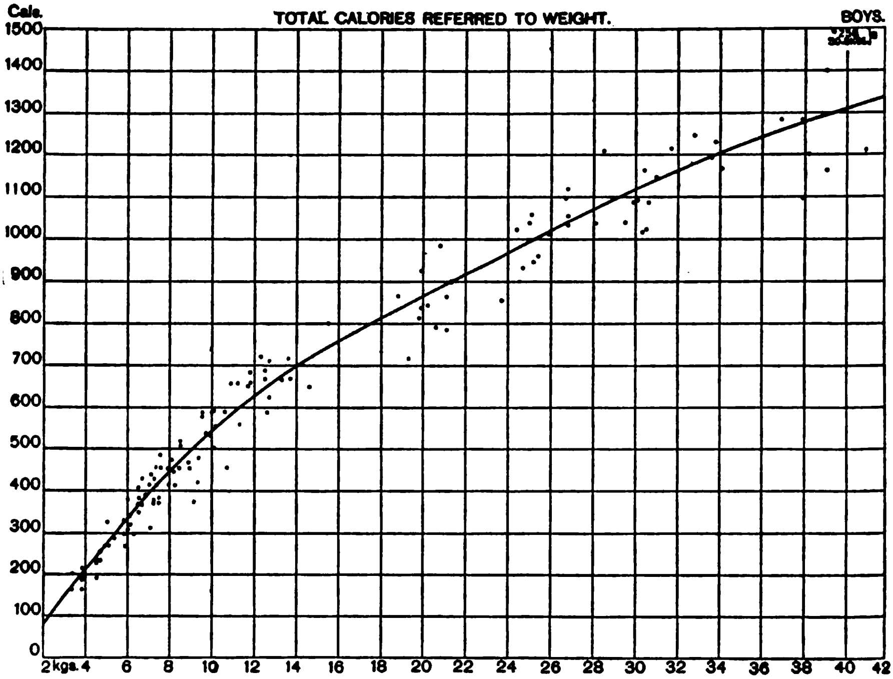

FIG. 26.—Basal heat production of boys per 24 hours referred to body-weight. Point inclosed in square signifies puberty established.

The general close agreement between the different points and the sketched central curve is rather striking, although at times the deviations amount to 150 or more calories. Thus, at 19 kg. one point varies considerably over 100 calories from the line, corresponding to a deviation of 15 per cent. Another child, weighing 38 kg., is 180 calories below the general line, while a third child, weighing 9 kg., is 125 calories, or 25 per cent, below the central line. Similar instances of values above the line may likewise be noted. While the child designated as No. 258, with a weight of 50.8 kg., seems on the chart to have a metabolism differing widely from the central tendency, it must be remembered that if the chart were extended to the 50 kg. range, the metabolism would be shown to be much nearer the central line, though still above it. On the whole, the values lie reasonably close either side of the line; indeed, so close that the use of this curve to predict the normal metabolism will be subsequently discussed. (See page 188.)

Attention should be called to the evidence in figure 26 of differences in metabolism, even with children of the same weight. In some instances, *i. e.*, with children weighing 38 or 39 kg., we find a range of from 1,100 to 1,400 calories, or a difference of 27 per cent; and at 21 kg. we have one value of 785 calories and another at 985 calories, a difference of 200 calories, or 25 per cent. At about 11 kg. we have a range from 450 to 660 calories, approximately 200 calories, or about 45 per cent. Thus we see that with certain individuals our extremes may be fairly wide. On the other hand, the general grouping of the points around the central line is suggestive of a clearly defined trend.

Since the general picture is so similar to that of the chart for calories referred to age, we apparently have here another expression of the fact that as the children increase in age they increase in weight, and that the age chart and the weight chart are more or less inseparable, since weight is inevitably correlated with age and heat production increases both with age and weight. It would be undesirable, however, even to imply that age and weight are of equal or, indeed, of comparable importance in determining basal metabolism. It has been shown with adults that there is a definite influence of age, with, on the average, an actual decrease in the daily heat production with men of about 7.15 calories per year and with women a decrease of 2.29 calories per year.[1] Still, this same analysis indicates that the influence of weight far exceeds that of age; hence we must conclude that with children the changes in metabolism noted with different ages are due primarily not to the age element, but to the fact that age changes concurrently with weight.

TOTAL CALORIES PER 24 HOURS REFERRED TO WEIGHT (GIRLS).

The values for the girls included in this study are charted in figure 27. The line representing the general trend of metabolism gives a picture of rather rapidly increasing metabolism until the weight of 10 or 12 kg., with a tendency thereafter for the metabolism to increase at a slower rate, which is still present when the weight limit of the chart (39 kg.) is reached. Practically, this chart should have ended at the weight of 31 kg., there being but two values retained beyond this weight.

The widest deviations of individuals from the general line are, for the most part, well within 100 calories, which, for the higher-weight ranges, represents a relatively small percentage deviation. A comparison of the percentage deviations for these children with those for adults has special interest, since with adults it was noted that the scatter of the individual points from the central line was very considerable. In consideration of the rapidly changing body-mass with children, the compact arrangement of the points in these charts has, however, a somewhat greater significance. With pronounced alterations in area, stature, and weight, such a stringent conformity to the central tendency may not be expected as with well-developed adults. So close are these points, on the whole, to the general curves for the boys and girls that the possibility is considered later of using the two curves for predicting the metabolism of children whose basal heat output is unknown. (See page 205.)

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 115.

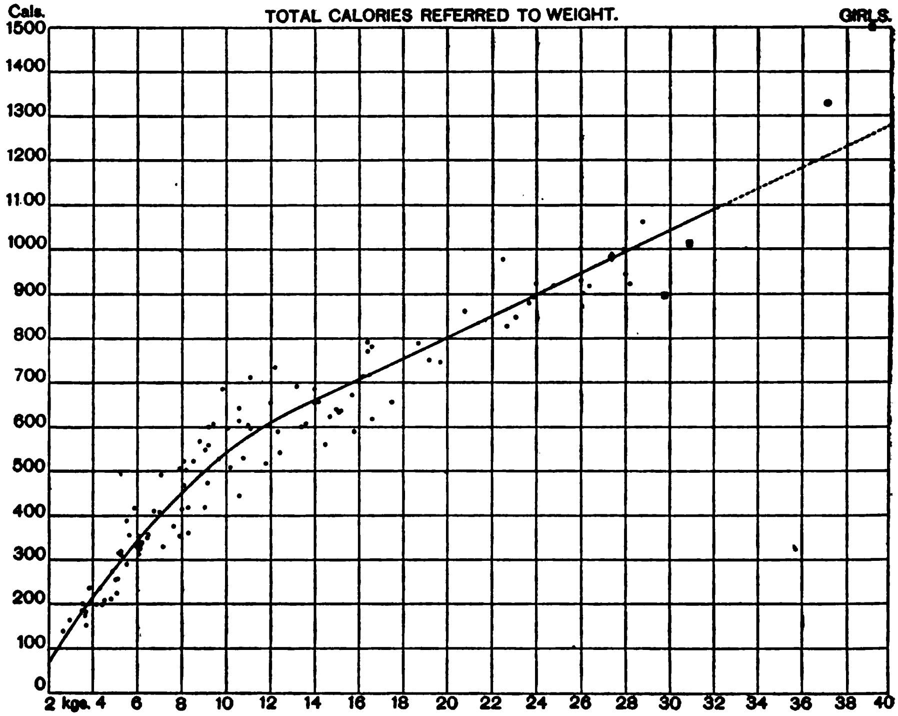

FIG. 27.—Basal heat production of girls per 24 hours referred to body-weight. Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 39.2 kg. (puberty).

TOTAL METABOLISM OF CHILDREN REFERRED TO WEIGHT (EARLIER INVESTIGATORS).

The special advantages of referring total metabolism measurements to weight rather than to age observed with the children in this research make it likewise important to inspect the values reported by other investigators on this basis. We have consequently plotted in figure 28 the values for boys obtained by other investigators. For purposes of comparison we have laid on the smoothed curve from the chart in figure 26, representing the general trend of the total metabolism of boys as found by us. With the exception of one child under 6 kg. of weight, all of the observations lie above the smoothed line. Since our curve has been carried only to 42 kg., five of Du Bois's boy scouts and one of Magnus-Levy and Falk's children are outside of this range. If the curve were projected, one of these values would lie approximately on the line, another somewhat below it, and four considerably above it. The high values noted on the basis of weight for the children studied by Magnus-Levy and Falk and by Du Bois have been criticized, the Magnus-Levy and Falk values by Harris and Benedict[1] and the Du Bois values in the historical section of this monograph. (See page 19.) The fact that practically all the values lie above the general trend found by us would imply again that our curve represents more nearly the true basal value than any curve that can be drawn from the earlier work, when the requirements for basal conditions were apparently not so rigidly adhered to.

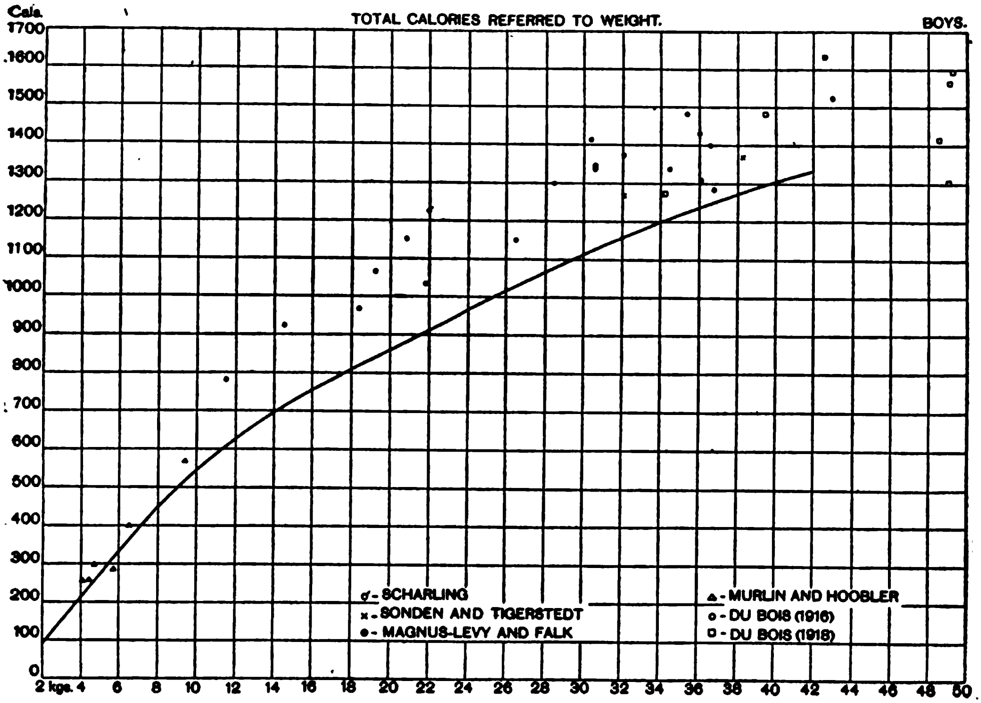

FIG. 28.—Basal heat production of boys per 24 hours referred to body-weight (earlier investigators).

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 235.

Although but few measurements with girls are available for this comparison, they have been plotted in figure 29 and the corresponding curve derived from our observations on girls has been applied. While the points all lie above our curve, they are for the most part somewhat closer to the line than was found with the corresponding values for boys. Almost no data are available for girls at the lower weights.

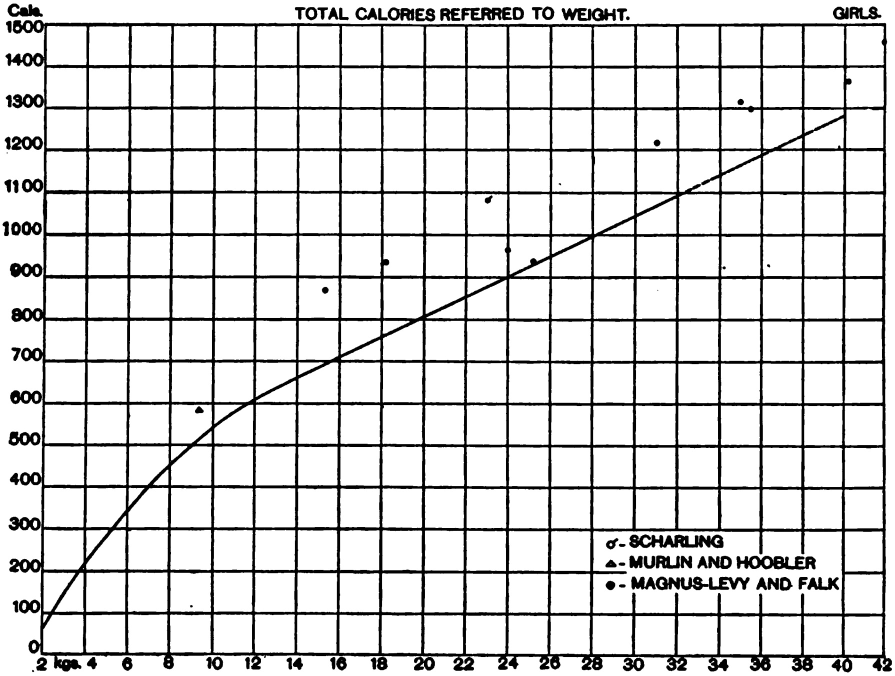

FIG. 29.—Basal heat production of girls per 24 hours referred to body-weight (earlier investigators).

From an inspection of figures 28 and 29, it would seem that the girls as a whole adapt themselves more readily to basal conditions, especially as to activity, than do the boys, since our series with girls more nearly corresponds with the scattered observations in the earlier literature than the comparison for the boys. The great irregularity in the grouping of points around the curves when total calories are referred to age, which is found in all three charts on this basis, leaves no doubt that the physiologically sound method of reference in metabolism measurements should be to weight rather than to age, for, as previously pointed out, although changes in age and weight are more or less closely correlated, the predominating factor influencing the basal metabolism of the growing child is undoubtedly change in weight, the change in age influencing the metabolism only indirectly as related to change in weight. The absence of some age influence *per se* is, however, by no means proved.

METABOLISM PER UNIT OF BODY-WEIGHT REFERRED TO AGE.

Since it was early recognized that large individuals produce more heat than small ones, the comparison of metabolism values on the basis of mass alone was introduced by some of the first investigators. Thus, we find that Forster[1] in his work with children, expressed the results obtained as metabolism per 10 kg. of weight, attempting thereby a rough grouping of all infants in a 10 kg. class. From this point the step was easy to consider all individuals on the basis of per unit of mass, and physiologists have since that time had a strong tendency to express the values of metabolism for comparative purposes on the basis of the metabolism per kilogram of body-weight.

A biometric analysis of the metabolism of adults has shown that weight, stature, and age have a specific influence upon metabolism. With adults, the stature of an individual does not appreciably alter. The age influence is small, though definite. The weight changes are considerable, but have rarely been studied with the same individual. On the other hand, with children we have relatively great changes in all three factors, weight, stature, and age, and consequently any comparative methods used for adults must always be subject to particular criticism when applied to children. It is of course physiologically of much interest to compare the metabolism of a man weighing, say, 90 kg. with that of a man weighing 45 kg., if only to find the difference in the absolute metabolism, which would naturally be assumed as greater with the heavier individual. But physiologists have also long sought for some reasonably definite relationship between the physical characteristics of individuals and their metabolism, the simplest of these obviously being body-weight. While the problem is particularly difficult with the age-range in our observations, it is of as great, if not greater, physiological importance to compare the metabolism of two children varying considerably in age as it is to compare the metabolism for the two men. Thus, the average 5-year-old girl weighs not far from 18 kg., and the average 12-year-old girl weighs approximately twice as much, *i. e.*, 35 kg. So we have here two individuals, one weighing twice as much as the other, as in the case of the two men.

Two bases for comparison have long been used by physiologists, both of which assume that a definite relationship exists between total metabolism and the physical characteristic of weight and total metabolism and the surface area of the body. More recently an entirely different conception has been introduced, in that a biometric analysis of the basal metabolism of a large group of men and women has demonstrated that with each sex there is a distinct correlation between weight and metabolism, between age and metabolism, and between stature and metabolism. Furthermore, by means of partial correlations, it has been clearly established that each of these factors, weight, stature, and age, has independent relationships. As pointed out elsewhere,[1]

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[1] Forster, Amtl. Ber. d. 50 Versamml. deutsch. Naturf. u. Aerzte in München, 1877, p. 355; also v. Ziemssen's Handbuch der Hygiene, Leipsic, 1882, 1, p. 76.

> "If a group of individuals of identical weight be examined, the taller individuals will be found to have the higher metabolism. If a group of individuals of the same stature be examined, the heavier individuals will be found to have the greater metabolism."

In considering the children observed by us, we shall attempt to analyze the metabolism changes upon these various bases. That which has the earliest historic interest and has been most persistently retained, perhaps, is the simplest and most obvious one, namely, that the larger individual has the larger metabolism; hence the metabolism has been referred to the unit of body-weight and commonly expressed as the metabolism per kilogram of body-weight. This comparison, unfortunately, has the underlying assumption, which we believe to be erroneous, that each kilogram of body-weight has the same heat-producing power. We know that with a thin man the proportions of fat, bone, and muscle differ greatly from those with a fat man. Differences of an even greater order may be noted when a normal, plump, healthy child is compared with an atrophic child, and the clinician hopes to obtain from the physiological studies such an estimate of normality as to allow him to make this comparison. Accordingly, this fundamental assumption of equality in the heat-producing power of the body-mass, with wide variations in the composition of the body, must always be considered as subject to severe criticism. With these mental reservations, we shall compare our children of different weights and ages on the basis of the heat production per kilogram of body-weight and examine, in so far as the data permit, the results obtained in the earlier studies.

CALORIES PER KILOGRAM OF BODY-WEIGHT PER 24 HOURS REFERRED TO AGE (BOYS).

While the age factor with adults has been shown to have a small influence, in that the heat production decreases annually with age, in the period of growth for boys it can easily be imagined that the influence of age would be larger than with adults. In comparing the total heat production of boys at different ages (see fig. 22), it was found that age changes were intimately connected with weight changes, but in the comparison of the data on the basis of heat per kilogram of body-weight, the weight element is in considerable part eliminated. The heat production per kilogram of body-weight for the boys studied by us at their various ages and weights has been plotted in figure 30, and we have here what may properly be termed a "scatter" diagram.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 102.

While a reasonably clear trend for the metabolism is shown in the charts plotted on the basis of total calories, it is only with great difficulty that one may discern a general trend in figure 30, which is at best only a conjecture. Still, the usual method was followed for sketching this composite curve. The line obtained is much more irregular than any of the curves thus far considered.

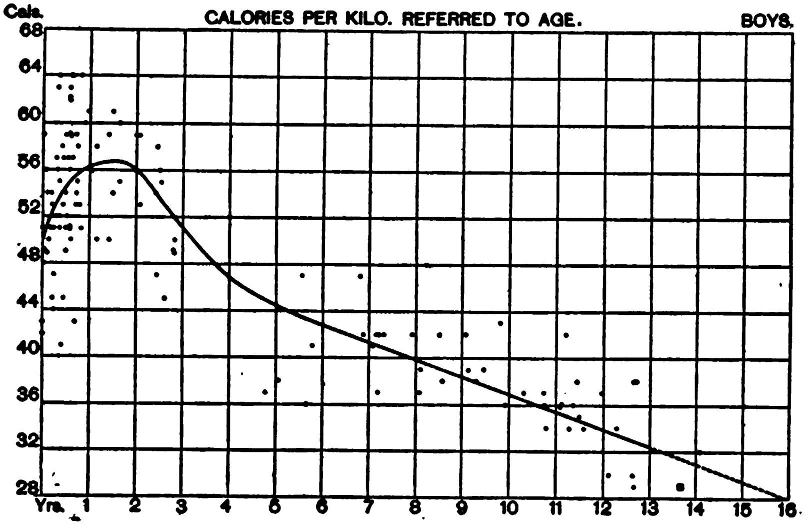

Fig. 30.—Basal heat production of boys per kilogram of body-weight per 24 hours referred to age.

Point inclosed in square signifies puberty established.

The values for the earlier months of life, as shown in the chart in figure 30, indicate a clear tendency for a lower metabolism per kilogram of body-weight than at the end of the first year, thus justifying the upward trend of the curve. Subsequent to 5 years, the values are definitely lower than those in the first 3 years of life. Although there is great irregularity in the dispersion of the points, it was thought best to represent the trend after 6 years by a straight line, for the irregularity noted in the distribution of the points is perhaps no greater than that found with adults. A most careful analysis of the material for adults indicated that the straight-line equation gave as close a representation of the changes in metabolism per kilogram of body-weight with changing years as could be expressed by a curve of a higher order. Still, the laying on of this curve must be looked upon only as an empirical representation of a general trend and not as a mathematically established average.

Of special significance in this chart, therefore, is first the extraordinary dispersion of the points about the smoothed curve. Whatever degree of regularity has been heretofore assumed by physiologists in the heat production per kilogram of body-weight, the chart certainly shows with children a great diversity with age changes. The figures indicate a somewhat lower general metabolism per kilogram of body-weight during the first 6 months, with the highest metabolism per kilogram throughout the age-range of this study to be at 1 or 2 years of age. While the values for the period from 3 to 5 years are but few in number, they indicate a rather rapid fall; after the age of 5 years the decline is definite, though not so marked. The small number of individuals studied over 13 years of age hardly justifies a continuation of this curve beyond that period.

The heat production per kilogram of body-weight has frequently been considered as somewhat of a physiological constant, but we find on this chart a range in values extending from 29 to 64 calories per kilogram, in other words, a variation of over 100 per cent. Even during the first year of life there is a range of from 41 to 64 calories. After the fifth year the range is from 29 to 48 calories. While the smoothed curve laid on this chart does imply a slight general trend, there is nothing here approximating mathematical constancy, and certainly nothing that can be considered as a physiological law establishing a relationship between the heat production per kilogram of body-weight and the age.

The charts comparing total calories do not permit a comparison of individuals at different weights or different ages; hence this method is of value, since it supplies some suggestion as to the relative intensity of metabolism at different ages. On the assumption, erroneous though it is, that each kilogram of body-substance has the same heat-producing capacity, one can conclude that at the age of 1 to 2 years there is a greater relative intensity of metabolism than at any other period of life up to 13 years, and that the young organism per unit of mass produces a larger amount of heat than does the older.

It would appear from this chart that with children we are dealing with physiological entities and not with crystalline structures, each having its mathematically established planes. Although the method of expressing the metabolism on the basis of per kilogram of body-weight permits a very gross comparison of different individuals, the entire absence of uniformity and the wide scatter of the points about the central tendency show that such comparison can have but very slight individual mathematical significance. Between the ages of 5 and 13 years, although the points are widely scattered, it would appear as if a straight line represented the trend as well as any other form of curve. This is of significance as being preliminary to the straight-line tendency exhibited with male adults, and this curve therefore brings out primarily the high metabolism per unit of mass noted with boys at about the age of 1 to 2 years.

CALORIES PER KILOGRAM OF BODY-WEIGHT PER 24 HOURS REFERRED TO AGE (GIRLS).

Our observations on girls at different ages, being practically as numerous as those of boys, allow us to study the caloric output per kilogram of body-weight as referred to age. In figure 31 we have plotted the individual points for all of our girls on this basis. The striking scatter of all these points makes it extremely difficult to lay on anything in the nature of a smoothed curve that could be considered justifiable. From the concensus of opinion of five observers, a curve has been sketched which indicates nothing more than a general trend.

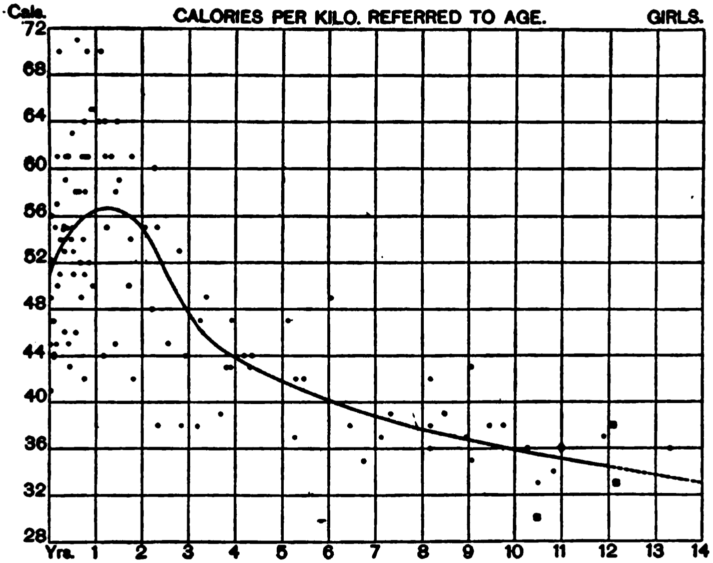

FIG. 31.—Basal heat production of girls per kilogram of body-weight per 24 hours referred to age.

Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 12 years 1 month (puberty).

During the first six months on the average there is a somewhat lower metabolism per unit of weight than appears later, with the highest values occurring at about one year. The general form of the curve is not unlike that in figure 30 for boys. Although it is hardly the place to emphasize a sexual differentiation, it is worth while indicating here that with boys the highest values lie at 64 calories, while with girls there are six of the individual points which lie higher than 64 calories, practically all of them being inside the first year.

When it is remembered that the element of weight is in large part removed by this comparison, one is impressed by the wide variations to be found in the calories per kilogram of body-weight of children of various ages. For example, at or about the age of 1 year we find variations ranging from 42 to 70 calories, and it is only after the age of 7 years that the individual points tend to lie reasonably close to the general smoothed curve.

From the general picture presented by the chart for girls, it can be seen that the conclusion drawn from that for boys still holds, namely, that the calories per kilogram of body-weight exhibit such wide deviations from a general mean as to make it impossible to conceive of anything approximating a physiological law associating the heat production per kilogram of body-weight with the age. The scattering of the points makes the laying-on of this smoothed curve a distinct violation of mathematics and open to severe criticism. We wish again to emphasize that the curves on all of these charts are not to be interpreted on the basis of mathematical accuracy, but simply to indicate the central tendency and general trend.

CALORIES PER KILOGRAM OF BODY-WEIGHT PER 24 HOURS REFERRED TO AGE (EARLIER INVESTIGATORS).

Since the measurement of the metabolism per unit of mass plays such an important rôle with the earlier writers, the comparatively few individual values found by other investigators with boys are plotted in figure 32. On this chart we have likewise laid our general line from figure 30. With the single exception of one value at the age of 2 months, no other point in the entire series lies below our general line up to the age of 13 years, but for the most part they lie very considerably above our line. Beyond 13 years two points obtained by

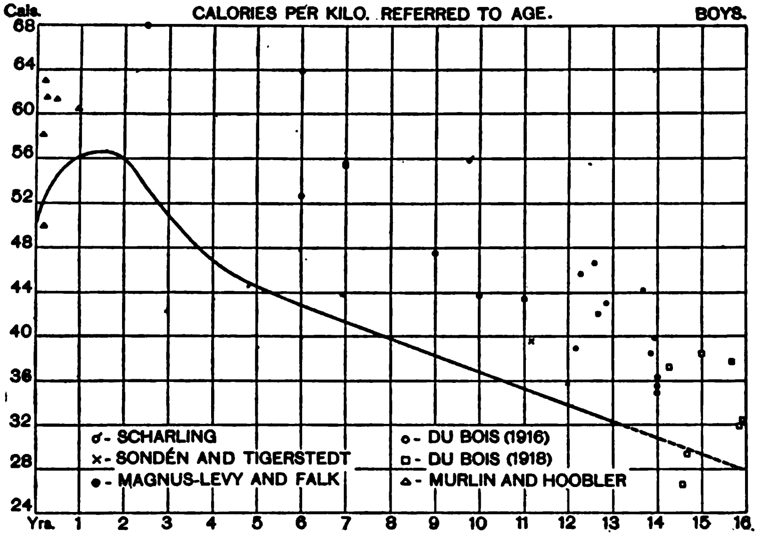

FIG. 32.—Basal heat production of boys per kilogram of body-weight per 24 hours referred to age (earlier investigators).

Du Bois with boy scouts in his second series of experiments indicate values a little below our projected general trend.

This comparison, in which the influence of variations in weight is in part eliminated, still shows that practically all of the values obtained in the earlier work are on a higher metabolic level than ours. We are thus forced to the conclusion that much of the earlier work was unwittingly affected by muscular activity to such an extent that it fails to meet modern requirements for basal metabolism measurements. Still, the general trend of the earlier work is not widely different from that observed in our research, for a smoothed curve passed through the points on the chart in figure 32 would be of approximately the same order, although at a higher level than that shown by our results. This suggests that the differences in the various series of observations are due wholly to differences in the degree of approximation to basal conditions. The earlier work does not, however, bring out the distinctly lower metabolism in the first few months of life which is so clearly shown by the general averages of our more numerous data.

The relatively few observations of earlier writers on girls make it seemingly unnecessary to burden this report with a reproduction of an additional chart comparing the values per kilogram of body-weight referred to age for these investigators. It is sufficient to state that all of the earlier values lie above our smoothed curve, with the exception of two of Magnus-Levy and Falk's girls at 11 and 12 years, both of which lie but little below. The points for the Magnus-Levy and Falk girls, however, are grouped about the curve with a distribution not dissimilar to that for our own values. In general, all the girls previously measured who were 10 years of age and over show a reasonably close agreement with our smoothed curve on the basis of calories per kilogram of body-weight.

The importance of studying the metabolism during youth was clearly emphasized in the classical studies of Sondén and Tigerstedt,[1] but owing to the absence of conditions prerequisite for the determination of basal metabolism, the values are not strictly comparable and only two could be used in the chart in figure 32. We have, however, selected minimum carbon-dioxide periods and computed the minimum calories per kilogram referred to age; these are plotted in figure 33 for boys. Upon the same chart we have laid our curve for basal metabolism of boys from 7 to 16 years and likewise included the values recently cited by Carl Tigerstedt[2] for boys from 9 to 14 years of age. This last citation is preceded by a careful statement as to the importance of muscular rest, and these values have accordingly been selected with this in mind. Similar results are shown in figure 34 for girls.

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[1] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 1.

[2] Tigerstedt, Carl, Ueber die Nahrungszufuhr des Menschen in ihrer Abhängigkeit von Alter, Geschlecht und Beruf, Helsingfors, 1915. See also Skand. Archiv f. Physiol., 1916, 34, p. 151.

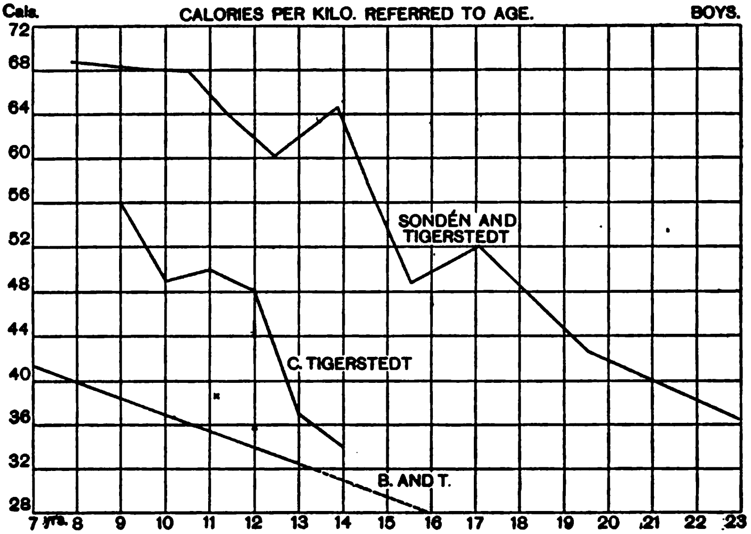

FIG. 33.—Basal heat production of boys per kilogram of body-weight per 24 hours referred to age (Sondén and Tigerstedt, C. Tigerstedt, and Benedict and Talbot).
The two crosses represent the values found by Sondén and Tigerstedt with boys during sleep.

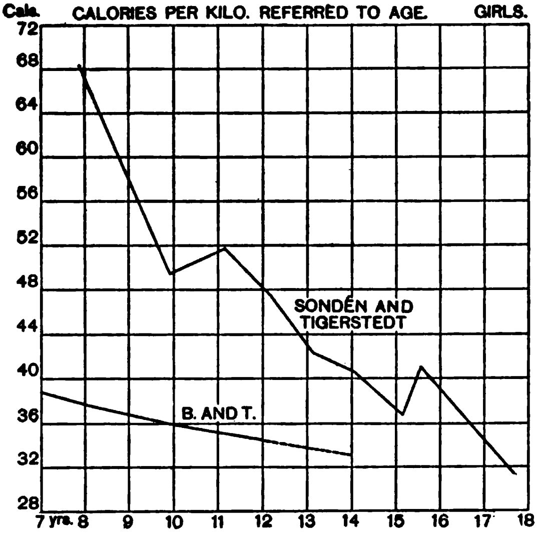

FIG. 34.—Basal heat production of girls per kilogram of body-weight per 24 hours referred to age (Sondén and Tigerstedt, and Benedict and Talbot).

The striking feature of these charts is the great difference between the values reported by Sondén and Tigerstedt and those in our smoothed curves. Of importance, however, is the fact that the values obtained by Sondén and Tigerstedt with two sleeping boys 11 and 12 years old, respectively, and indicated in figure 33 by small crosses, lie close to our line. This explains not only why our values are lower than the other values found by Sondén and Tigerstedt, as well as the composite values derived by Carl Tigerstedt from the observations of Hellström, Rubner, von Willebrand, and Sondén and Tigerstedt, but likewise, we believe, why they are lower than the results of the observations of Magnus-Levy and Falk, Du Bois, and others. When the experimental conditions under which the early investigations were made more nearly approach basal requirements the values are found to be more in line with our smoothed curve. As will be seen later (page 209), while we must disregard in large measure the earlier work as a standard for basal metabolism, these results have a great practical value for estimating the probable 24-hour total daily requirements of the growing, active child. The two series thus supplement each other perfectly.

METABOLISM PER UNIT OF BODY-WEIGHT REFERRED TO WEIGHT.

In referring the metabolism of children to age, undue stress is laid upon the age element; from the earlier analysis of the metabolism of adults of different ages, we have every reason to believe that, while the age factor is by no means to be ignored, it does not in any way compare with the weight factor. With youth, gross differences in metabolism are noted with variation in age, but these differences may in large part be ascribed to the concomitant weight changes, since a child changing in age is likewise changing in weight. Theoretically, at least, a more logical comparison of the metabolism of different children is not upon the basis of age, but upon weight. The weight element is in part removed by computing the calories per kilogram of body-weight. Even then, strictly speaking, the comparison still is best made with children of various weights rather than of various ages. From the analysis of the charts in figures 22 to 32, it is seen that in general the pictures of the metabolic changes for the various weights are not unlike those for age, and hence we are prepared to find the curves for the calories per kilogram of body-weight referred to body-weight somewhat similar to those in which these values are referred to age.

Our values for boys have been plotted in figure 35 and a smoothed curve sketched to indicate approximately the general trend. The very wide scatter of the points, particularly below 18 kg. in weight, is worthy of special notice and is fully in accordance with variations noted in the age charts. It seems reasonably clear that at the weights under 6 or 7 kg. there still is a tendency for the metabolism to be somewhat lower per kilogram than a little later. Hence we feel that the rise in the sketched curve is perfectly justifiable. The maximum occurs at about 7 or 8 kg., this approximating the average weight for children of one year. Thence the curve decreases with a reasonable degree of regularity. Not until 24 kg. and over is reached do the points lie sufficiently close to the central line to give a clear idea of physiological regularity in the metabolism per kilogram of body-weight referred to the total weight.

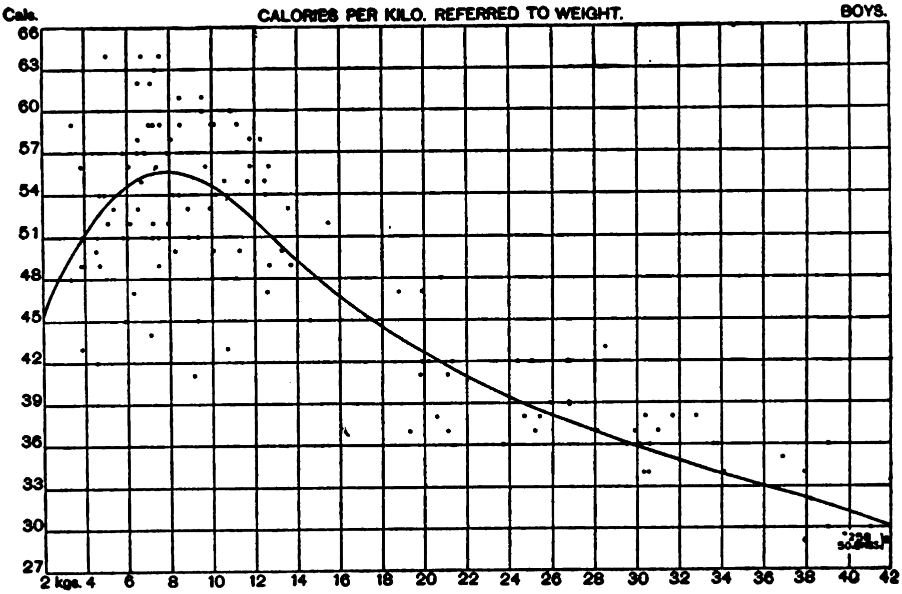

FIG. 35.—Basal heat production of boys per kilogram of body-weight per 24 hours referred to weight.

Point inclosed in square signifies puberty established.

The suggestion of sexual differentiation between boys and girls, even at the early ages, noted in the calories per kilogram at the age of one year, makes it desirable to consider by itself the metabolism per kilogram of the girls at different weights. These values are plotted on the chart in figure 36, together with our smoothed curve indicating the general trend of metabolism. The most pronounced feature of this chart is the wide scatter of the individual points from the smoothed curve, this being even more evident for the girls than for the boys. Still, it is reasonably clear that the general trend shows a rise between 3 and 8 kg., where the maximum is found, with a clearly defined decrease thereafter to about 26 kg. Subsequent to that point the line appears to be reasonably level, but the number of points available beyond 30 kg. is so few as hardly to justify discussion. Up to 18 kg. there is such a wide dispersion of points about the smoothed curve that no conclusion may be drawn regarding a physiological law, even though the general trend seems to be established with reasonable clearness. The correlation between the calories per kilogram and the body-weight is not, therefore, a very striking one. While it is sufficient to indicate a low metabolism at the early weights, with a rise to a maximum at about 8 kg., so far as the individual is concerned one can not predict at the weight range of 6 to 8 kg. whether the metabolism will be 43 or 70 calories per kilogram. After 18 kg. there seems to be a reasonable degree of compactness in the grouping of the individual points.

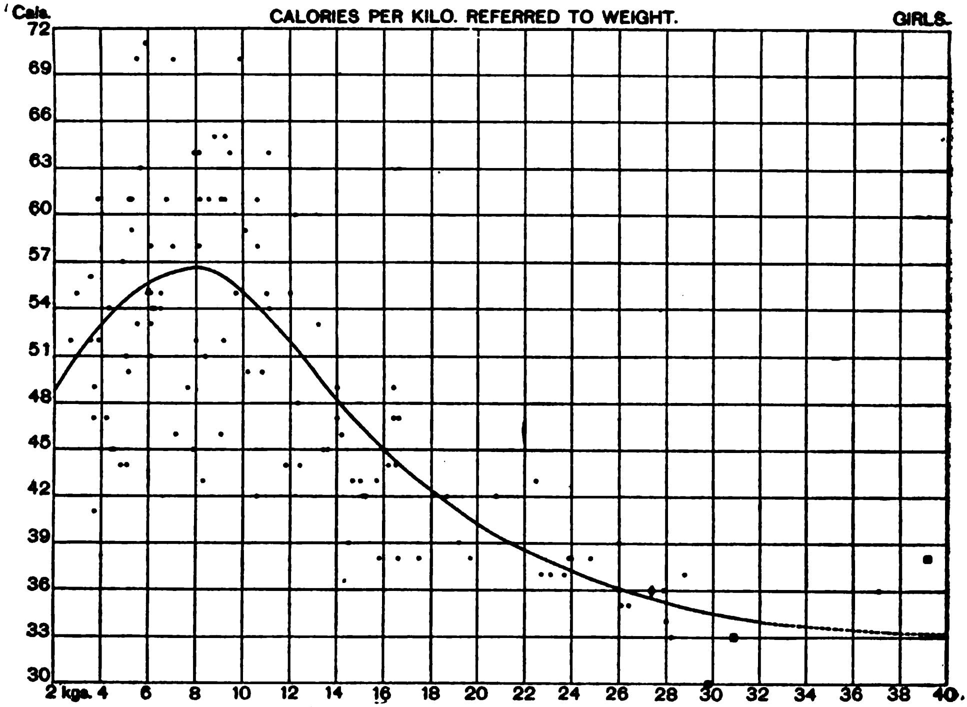

FIG. 36.—Basal heat production of girls per kilogram of body-weight per 24 hours referred to weight.

Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 39.2 kg. (puberty).

At the same weights, very great differences in metabolism are noted in both figures 35 and 36, even with the unit here employed, namely, the calories per kilogram of body-weight. It is, however, clearly established from both curves that the metabolic activity per unit of weight is very much greater at the lower weights than at the higher. This is in full conformity with the experience with adults, the heavy individuals having a lower heat production per kilogram of body-weight than the light men and women. A popular interpretation of this phenomenon with adults has been that with the heavy individuals there is a large proportion of inactive fat, which does not materially contribute to the heat production. This explanation, while reasonably clear for adults, does not, we believe, hold true with children, for on this basis we should expect the children with the higher weights to have a much larger proportion of inactive body-fat than the smaller younger children, and in consequence their heat production per kilogram of body-weight would be lower. As a matter of fact, physical examination has shown that young children usually have a much larger proportion of fat than older children, so that the phenomenon exhibited in figures 35 and 36 is exactly contrary to what would be expected if one considered solely the proportion of fat in the body.

At this point a note of caution must be sounded. In our discussion of the conditions laid down by us as the basal requirements, we have stressed considerably the fact that with young children one of the prerequisites for basal measurements can not be satisfactorily met, *i. e.*, the post-absorptive condition. With adults, measurements are made approximately 12 hours after the last meal, when, it has been experimentally demonstrated, the stimulus of the previously ingested food has practically disappeared. Our observations show that the younger the children, the more difficult it is to secure long periods without food. Furthermore, with young children, particularly, it is difficult to determine exactly at what hour the stimulus of the previously ingested food ceases and the point at which the stimulus of the ever-occurring incipient acidosis begins. Since the influence of the previously ingested food is in inverse proportion to the age of the children included in this study, one must bear in mind that the high portion shown in both curves in the two figures 35 and 36 is undoubtedly in part influenced by the previous ingestion of food. We believe, however, that if a correction were possible for the influence of food, on the percentage basis this part would still lie somewhat above that for the older and heavier children. Furthermore, we have every reason to believe that the values observed at the earlier weights (from 3 to 5 kg.) were fully as much affected by the previous food as those between 6 and 8 kg., and there is clear evidence of a somewhat lower metabolism at these weights. While, therefore, the previous ingestion of food unquestionably raises somewhat the level of the curve showing the general trend of metabolism per kilogram of body-weight, probably no theoretical correction could remove all of this difference, especially as we have likewise a somewhat compensatory effect due to the fact that many of our younger children were in deep sleep, a condition that we believe definitely lowers the metabolism. So while our children could not be compared on the basis of a "post-absorptive condition" with adults, for the most part they were asleep and had a somewhat lower metabolism due to the specific effect of sleep than did the adults, who were for the most part awake.

CALORIES PER KILOGRAM OF BODY-WEIGHT PER 24 HOURS REFERRED TO WEIGHT (EARLIER INVESTIGATORS).

The general trend of the calories per kilogram of body-weight referred to weight may be compared with the individual points noted by other observers. This has been done for boys in figure 37 for the weight ranges up to 43 kg. To avoid enlarging this chart unduly, it was necessary to omit a number of values obtained by Du Bois and published in the second paper on his studies with boy scouts.[1] The four boys who were outside of the weight-range studied by us gave the values shown in table 29.

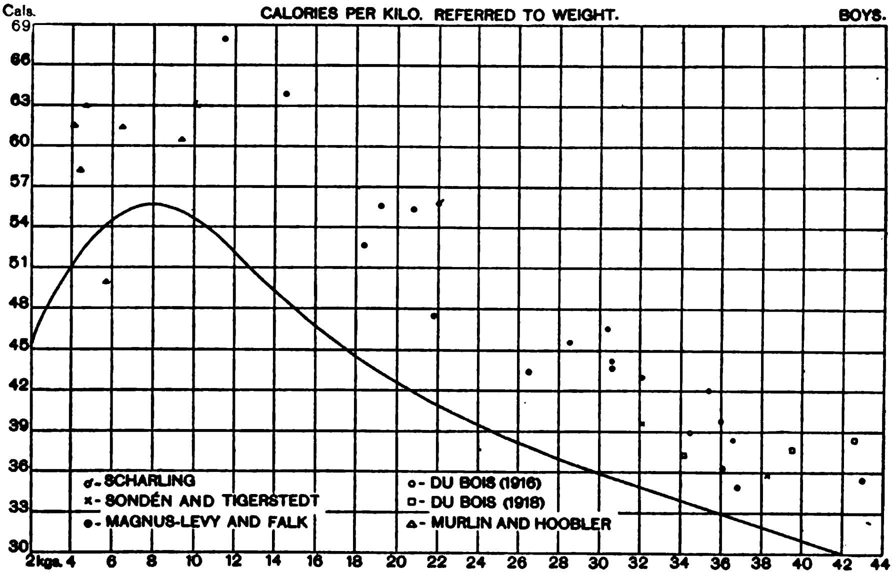

FIG. 37.—Basal heat production of boys per kilogram of body-weight per 24 hours referred to weight (earlier investigators).

TABLE 29.—*Values outside weight range in figure 37 (Du Bois).*

Subject.	Weight.	Heat per kilogram per 24 hours.
	kilos.	*cals.*
R. M.	49.1	26.6
R. F.	48.6	29.3
H. B.	49.1	31.9
H. K.	49.3	32.4

Aside from the values in table 29 and the infant of 5.5 kg. shown on the chart, all the points lie very considerably above our smoothed curve. If an approximate line were to be laid through these earlier values, it would follow with reasonable regularity at a higher level that laid down from our observations. It therefore seems clear, from all observations, that the metabolism per unit of body-mass is noticeably higher at 6 to 8 kg. of weight than at any other time of life. Our curve indicates that the metabolism is lower from 3 to 5 kg. than from 6 to 8 kg., but this is not shown by the earlier work. The gradual fall from 8 to 42 kg., at which point our observations end, is also apparent in all the observations. From the comparison of the calories per kilogram of body-weight in all the series, the general picture is thus essentially the same, and the newer data simply extend and confirm the earlier observations. The striking feature of this comparison is that the new work shows a distinctly lower level all along the line and brings out the lower metabolism during the first few months of life.

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[1] Olmstead, Barr and Du Bois, Arch. Internal Med., 1918, 21, p. 621.

The scarcity of earlier material available for comparison does not justify publishing here a chart for girls, but such a comparison has been made. Two of the values obtained by Magnus-Levy and Falk for girls weighing between 40 and 42 kg. lie but little above our curve. In general, the points for girls up to 40 kg., though above our line, lie fairly close to it, and are not more widely scattered than our own observations. The number of points is so small, however, that they give no suggestion of a general trend, but, so far as they go, they are in fair conformity with our curve and indicate a higher metabolism at the lower weights.

Notwithstanding the objections raised in earlier paragraphs regarding the probable influence of food, the evidence in all the observations demonstrates that there is a profound physiological difference in the metabolism of children weighing 6 to 8 kg. from that obtaining at any other period of life. If correction could be made for the composition of the body, it would appear that (per unit of weight of body-material other than fat) the metabolism would be even greater at the early weights and that undoubtedly with these weights (6 to 8 kg.) there is greater metabolic intensity per unit of active protoplasmic tissue than at any other point in the life of youth.

In an earlier report[1] we emphasized the extraordinarily low heat production of new-born infants, particularly on the first day of birth, attributing this in part to the temperature changes and perhaps weak condition of the organism after the birth and bath. It would seem as though this lower metabolism is characteristic of very young children and that the metabolism per unit of mass gradually increases until about the age of 1 year, or a weight of 6 to 8 kg., and thereafter steadily declines throughout the period of youth.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, pp. 103 and 118.

RELATIONSHIP BETWEEN SURFACE AREA OF THE BODY AND METABOLISM.

For decades the surface area of the body has by many physiologists been considered to have an intimate (in fact, a determining) relationship with the heat production. An extensive critique[1] of the body-surface law makes it unnecessary here to do more than to summarize in the following manner:

Height and weight have independent influences upon metabolism; body-surface, with its rather close relationship to weight, likewise has an apparent relationship to metabolism. Since body-surface represents more nearly a general morphological law of growth than body-weight does, the relationships between accurately measured body-surface and metabolism are frequently much closer than between body-weight and metabolism. Biometric analysis has shown, however, that certainly with the older methods of estimating body-surface, namely, the Meeh formula with its several constants,[2] body-weight and body-surface are equally closely correlated with heat production. When more exact methods for estimating body-area are used, particularly the linear formula and the resultant height-weight chart of Du Bois,[3] the correlation between area and metabolism is slightly better than that between weight and metabolism, particularly if the method employing regression equations suggested by Harris and Benedict[4] be employed. The earlier estimates of body-surface area (from the Meeh formula) are so erroneous and the factors have such large coefficients of variation that at best they are only rough approximates, and the modern physiologist may well disregard completely all consideration of body-surface as calculated from the Meeh formula.

The freeing of physiology from the cumbersome, wholly erroneous method of Meeh is due to the admirable work of D. and E. F. Du Bois,[5] who, by an extensive series of painstaking measurements of surface and casts from the surface of the body, have established a method of estimating the surface area of the body with a very considerable degree of accuracy. This method agrees perfectly with an entirely different method of measurement based upon a photographic procedure.[6] It should be stated, however, that the photographic method could not have been developed without the work of the Du Boises. As a result of the critique of the body-surface law presented by Harris and Benedict, we believe that the accurate measurements of body-surface made possible by Du Bois may legitimately be used in a manner heretofore never practicable in metabolism experiments, provided that they are considered as *physical* measurements and with no erroneous conceptions as to the existence of a causal relationship between surface-area and heat elimination.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 129.
[2] Meeh, Zeitschr. f. Biol., 1879, 15, p. 425.
[3] Du Bois and Du Bois, Arch. Intern. Med., 1916, 17, p. 863.
[4] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 188.
[5] Du Bois and Du Bois, *loc. cit.*
[6] Benedict, Am. Journ. Physiol., 1916, 41, p. 275.

Nearly all of our records of the surface areas of the children in this research, especially those for children above 1 year of age,[1] are based upon actual measurements of the surface-area by the Du Bois linear formula, and hence represent true *physical* measurements rather than computations from body-weight, which so long supplied the only basis for body-surface estimates. With our children, therefore, this accurately determined physical measurement may legitimately be employed exactly as we used the body-weight; if we so chose, we could likewise use the stature. Since the preponderance of evidence is slightly in favor of the correlation between body-surface accurately measured and basal metabolism on the one hand, and body-weight and basal metabolism on the other, a comparison of the surface-area and total metabolism is of physiological interest.

For practical use it is highly desirable to determine a normal trend of basal metabolism referred to some simply measured factor, such as weight, for the purpose of predicting the heat production of a subject whose weight is known but whose metabolism has not been measured. The multitudinous measurements involved in the Du Bois linear formula may therefore, in many instances, rule out the possibilities of comparing the measured surface-area and the total metabolism, or using the measured surface-area as a unit for estimating basal metabolism, as has so long been attempted from either body-weight or from the surface-area as computed by the Meeh formula.

In discussing our values on the basis of body-surface, it should be emphasized again that body-surface must be looked upon simply as a physical measurement approximating perhaps more closely the general morphological law of growth than does body-weight, and hence by this very fact, perhaps, giving a somewhat better idea of the relationship between the mass of active protoplasmic tissue and heat production than would the weight alone. We believe there is no causal relationship between body-surface area and heat production. All of our experimental evidence, not only for children but for adults under various conditions of nutrition, implies that the production of heat in the body is not determined by the loss. Even if it were granted, for the sake of argument, that the reverse is true, the physical and physiological factors influencing the heat loss from the surface of the human body are so different at different parts of the body as to preclude any generalization that equal areas result in equal heat loss. With this explanation clearly in mind, we may proceed to an analysis of the data obtained in this study, using the *measured* body-surface area as the unit of reference.

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[1] For 20 boys and 19 girls, nearly all of them very young, the body-surfaces were computed by the Lissauer formula. The data given for these children do not therefore represent actual measurements. (See tables 27 and 28, pp. 116 and 120.)

TOTAL CALORIES PER 24 HOURS REFERRED TO ACTUALLY MEASURED BODY-SURFACE AREA (BOYS.)

Employing the body-surface areas actually measured by the method of Du Bois, we have plotted in figure 38 the total heat per 24 hours and the actually measured body-surface areas for all of our boys. As with the other charts, a smoothed curve has been laid on, approximating as closely as possible the central tendency. In plotting these values we have followed the scale adopted by Harris and Benedict[1] of considering one-tenth of a square meter and 100 calories heat production as of equal value.

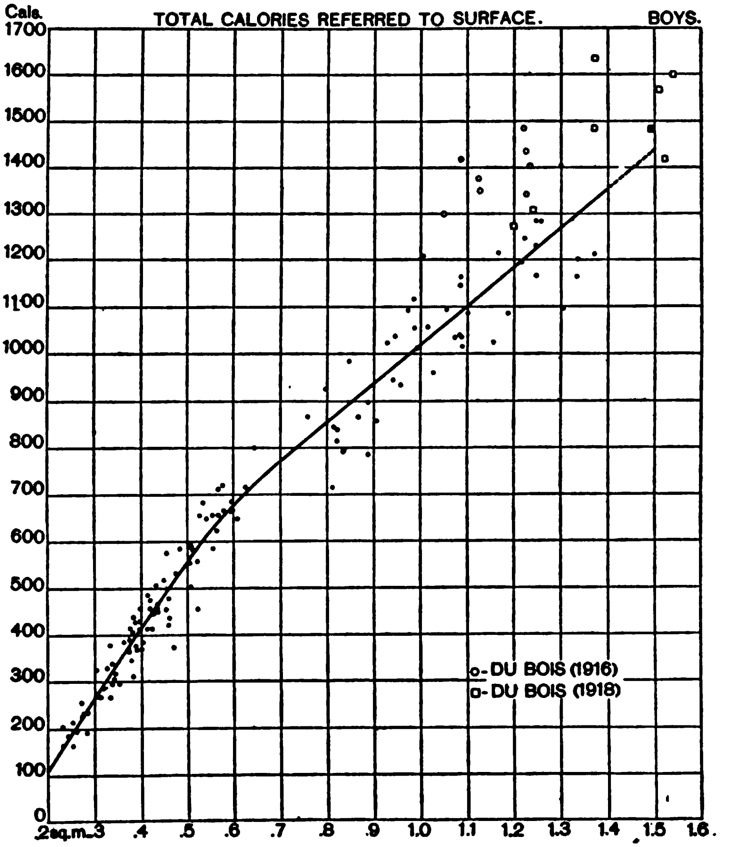

FIG. 38.—Basal heat production of boys per 24 hours referred to body-surface. Point inclosed in square signifies puberty established.

In contradistinction to the results obtained on adults,[2] the tendency of the metabolism is not in a straight line, but in a distinct curve, a curve strikingly similar in character to that found for the boys when the total calories were referred to weight in figure 26 (page 140). Since there is a close relationship between surface area and weight, this is not surprising, but it is important to note the scatter of the various points about the hypothetical smoothed curve. If the heat production is more closely proportional to the surface area than it is to the body-weight, we should logically expect a closer grouping of the points around the curve. A superficial inspection of the curves in figures 38 and 26 does not indicate that the scatter varies much in the two curves. If anything, it would appear that the points lie closer to the curve in the body-weight chart (fig. 26) than in the body-surface chart (fig. 38). The question of absolute scale values for ordinates and abscissæ enters here, however, and since subsequently both of these charts and smoothed curves are put to special use in an attempt to predict the heat production of the various children, further discussion at this point is unnecessary.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 157, diagram 26.

[2] Harris and Benedict, *loc. cit.*

The smoothed curve indicates a decidedly rapid increase in metabolism with increasing surface area up to about 0.6 square meter. Thereafter, although there is an increase in heat with larger surface, it is somewhat less in degree, as indicated by the sketched curve. Considering the variations in total calories for boys of like surface, we find some striking differences. For example, with the surface of 1.3 square meters, one boy has a heat production of 1,096 calories and another of 1,401 calories, a difference of 28 per cent. Again, at about 0.80 to 0.85 square meter, we have variations from 716 to 984 calories, a difference of 268 calories, or about 37 per cent; while at approximately 0.53 square meter we have a range of 456 to 684 calories, a difference of 228 calories, or 50 per cent.

These percentage differences are essentially of the same order as that noted in discussing the chart showing the relationship between weight and total calories (fig. 26, page 140). Indeed, by reference to the discussion on page 141, it will be seen that the differences there were, if anything, somewhat less. So far as this picture thus far goes, the evidence is slightly in favor of a greater degree of regularity in the relationship between heat and weight than between heat and body-surface, even though we are now referring to body-surface accurately measured and not approximately computed. A more rigid test of this, however, will be made when we come to consider in a subsequent section the utilization of the general smoothed curves in figures 26 and 38 as a basis for predicting the heat production of unknown subjects. What is of special physiological significance, however, is that the general picture presented by the chart in figure 38 indicates that the heat production referred to surface area is almost identical with that in which reference is made to body-weight.

Extremely few children studied by earlier investigators can be compared to our measurements. They are confined exclusively to the series of boys studied by Du Bois and his collaborators, whose body-surface areas were actually measured. If any attempt were made to use the values found by Magnus-Levy and Falk, it would be necessary to calculate the probable surface area based only upon the measurements given by Magnus-Levy for the weight and height of the children studied. Our analysis of the anthropometric data obtained in our studies shows us that from the weight alone we can compute reasonably close values for practically all children whose weight and sex are given,[1] and confirm them by inspection from some of the data actually obtained in our own series. Still, we do not wish to confuse the comparisons made in figure 38 by introducing *computed* surface areas, but do emphasize the fact that we are dealing here with a relatively recent physical measurement of children, namely, the surface-area by the Du Bois method. The values for Du Bois's 1916 and 1918 series for boy scouts have, for convenience, been included in figure 38, but it should be stated that these points were not laid thereon until after our smoothed curve was prepared.

Though the range for our own values for surfaces, ages, or weights do not justify extensive comparison with the 1918 series of boy scouts studied by Du Bois, we have plotted the latter in figure 38 for purely comparative purposes. It is seen that in almost every case the values found by Du Bois in both series of experiments lie above our smoothed curve. While a few of these lie fairly close to the curve, most of them lie considerably above it, indicating a metabolism of boys with these measured surfaces noticeably higher than that found by us.

Although it is probable that physiologists as a rule will not in the future make the Du Bois measurements a part of their regular records, such measurements are strongly recommended. At present the whole question as to the best index of physical character to correlate with measured metabolism is still in abeyance. As pointed out earlier (see page 53), the Du Bois measurements have a specific value entirely aside from that connected with the computation of the body-surface, in that they give typical girths and lengths which are of importance for indicating the several stages of growth. We strongly urge all pediatricians to include these measurements in their records and in detail. With the accumulation of a mass of data on this subject, further comparisons may be made, with important deductions to be drawn therefrom. Now that the Du Boises have given us an accurate physical measurement of surface-area, and as this measurement more probably approximates the true growth-changes than the measurement of mere weight, the significance of surface-area measurements *per se* should not be lost sight of by any worker in metabolism.

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[1] See tables 12 to 15, pages 54 to 62.

TOTAL CALORIES PER 24 HOURS REFERRED TO ACTUALLY MEASURED BODY-SURFACE AREA (GIRLS).

The extended series of Du Bois measurements were likewise made for most of the girls in this study, thus again permitting the comparison of the metabolism with actually measured surfaces. These data are brought together in figure 39, upon which we have laid a curve showing the general trend. There is clear evidence of a general increase in metabolism with increasing body-surface, and the curve is not unlike that found for boys in figure 38. It also bears a striking resemblance to that found when the heat production was referred to body-weight with both boys and girls (figs. 26 and 27). The variation of the points above or below the central line is apparently not unlike that with the corresponding curve for body-weight (see fig. 27), and they scatter with reasonable regularity about a fairly straight line. Especially divergent results are found at 0.52 square meter, and the two points showing a surface area above 1.2 square meters seemingly lie rather high. Evidently further observations are necessary with the

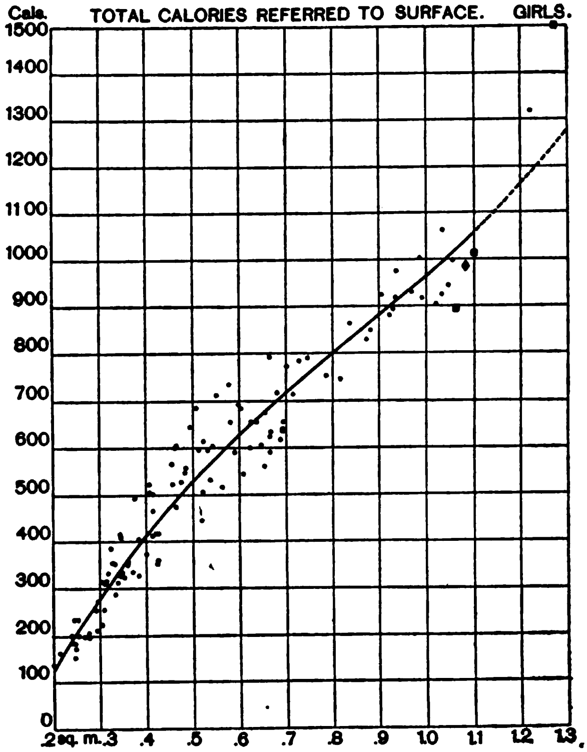

Fig. 39.—Basal heat production of girls per 24 hours referred to body-surface. Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 1.272 sq. m. (puberty).

larger surface-areas to project this line properly. Hence we have purposely ended it at an area of 1.1 square meters.

The main conclusions to be drawn from this chart, therefore, are that there is a distinct tendency for the metabolism to be increased as the surface-area increases and after the lowest areas it is a reasonably straight-line function, so far as the general drift is concerned, up to areas of 1.1 square meters. Individual points, especially at the lower areas, lie so far from the general line that it would be difficult to conceive of any physiological regularity that would suggest an intimate relationship between surface-area and the total calories.

Since none of the observations of the basal metabolism of girls in the literature were accompanied by surface-area measurements, no points for earlier values are placed on this chart and no textual discussion is deemed desirable, as we are dealing here with measured metabolism on the one hand and measured body-surface on the other.

CALORIES PER SQUARE METER OF BODY-SURFACE REFERRED TO BODY-SURFACE.

From the charts comparing total heat with measured surface-area, it is clear that the larger areas give the larger total heat production and that there is a tendency above the lower areas to a straight-line relationship, yet the comparison between the heat production per square meter of surface with the total surface shows these relationships much more clearly. Accordingly we have plotted the calories per square meter of body-surface referred to the surface, in figure 40 for the boys and in figure 41 for the girls.

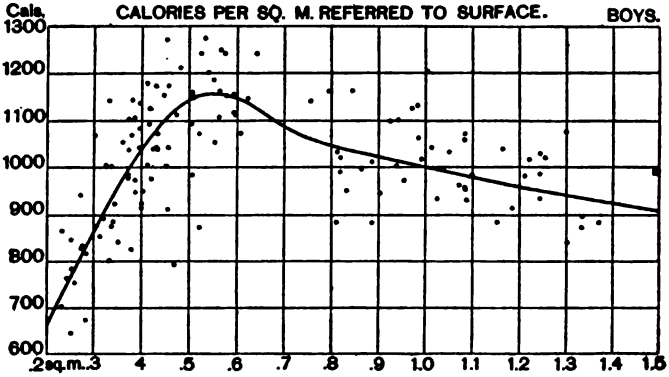

FIG. 40.—Basal heat production of boys per square meter of body-surface per 24 hours referred to surface.

Point inclosed in square signifies puberty established.

In figure 40 it is perfectly obvious that a straight-line curve or anything approximating a straight line will not correspond with the general trend. The sketched curve shows a rise in the calories per square meter with increasing area up to about 0.5 square meter;

thereafter there is a tendency for a slow but reasonably regular fall with increasing areas. The scatter of the points about this central line is very wide. If we take tentatively the line corresponding to 1,000 calories per square meter as running through approximately the center of the curve, the deviations either side of this line exceed 10 per cent in a large number of cases; for the children with the smaller body-surface they exceed plus or minus 25 to 30 per cent. The chart is important, however, in indicating substantially the earlier findings on the body-weight charts, in that with small surface-areas there is a greater intensity of metabolism per unit of surface, not forgetting the intimate relationship between surface and weight, and that this does not depend upon a causal relationship between surface-area and heat-loss. While this chart is not readily compared with other charts on the weight and age bases, it is clear that the scatter of the points is so great as to rule out any conception of a physiological law indicating relationship between the heat production per unit of surface and the actual surface as measured on the child.

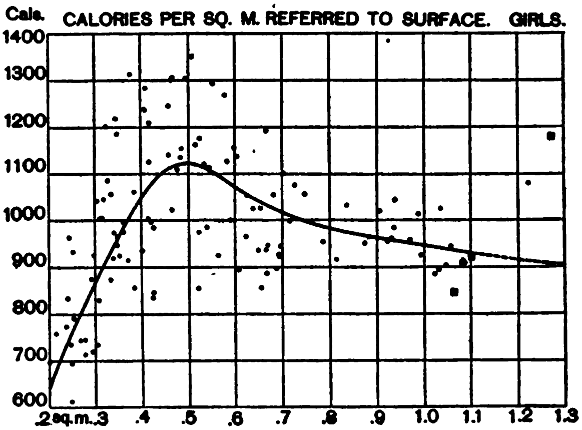

Fig. 41.—Basal heat production of girls per square meter of body-surface per 24 hours referred to surface.

Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 1.272 sq. m. (puberty).

In considering the calories per unit of surface-area referred to total area with girls (fig. 41), the characteristic wide scatter of points noted with boys is likewise here observed. While the line corresponding to 1,000 calories would roughly fit into the general middle of the curve, the deviations either side of this point range from 0 to nearly 40 per cent for the children of smaller body-surface but from 0.7 to 1.1 sq. m., the points group themselves somewhat better about the central line than they do with boys. The specific high metabolism with the smaller children and the absence of any regularity in the chart as a whole which would suggest a physiological law should be emphasized.

We believe that this is the first time that actually measured surfaces have been so extensively applied in comparisons with the simultaneously measured total calories. So far as the total calories are concerned, the general trend with both boys and girls is not unlike that for the total heat referred to weight. So far as the calories per square meter referred to area are concerned, the deviations from the central line are too great to permit of any theorizing as to the existence of a strict physiological relationship between heat production and surface area.

Comparison of Caloric Output per Square Meter of Body-surface with Total Body-Weight.

In the discussion of the charts dealing with body-surface thus far, we have seen that with increasing body-surface there is an increased total heat production, but when the calories per square meter of body-surface are referred to the surface, the general trend shows an increase in the metabolism to an area of 0.5 sq. m., and thereafter a definite decrease. These results throw absolutely no light upon the possibility of a relationship between area and heat production, for the surface may be simply another approximate expression of increasing body-mass, and particularly the mass of organic protoplasmic tissue

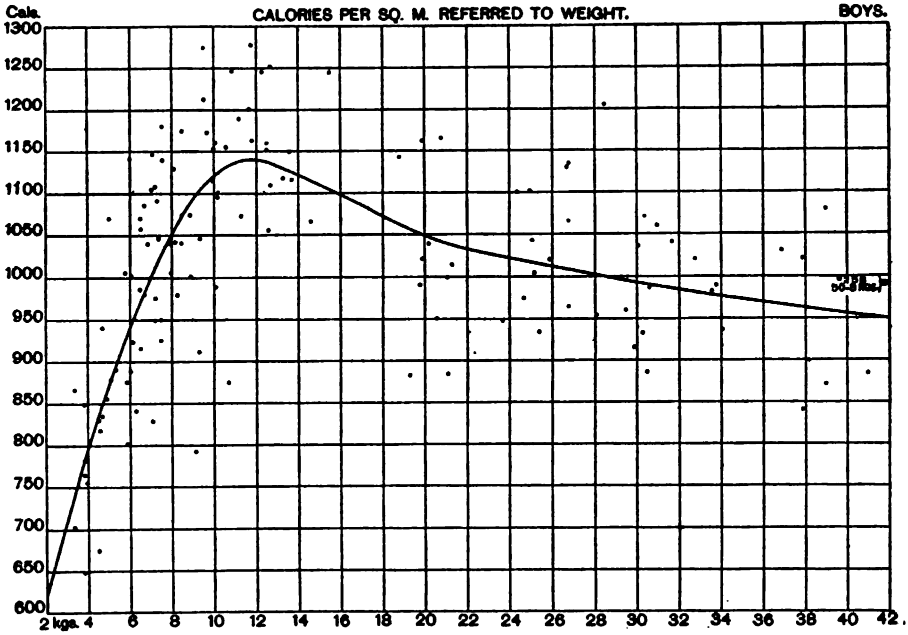

Fig. 42.—Basal heat production of boys per square meter of body-surface per 24 hours referred to body-weight.

Point inclosed in square signifies puberty established.

participating in heat production. Accordingly a comparison of the heat production per square meter of body-surface with children of different weights has a special interest. This comparison is made for the boys in figure 42.

The wide scatter of points on this chart makes the drawing of any smoothed curve very problematical. About the only clear feature of the plot is that a straight-line curve will not represent the general trend, for there is decided evidence of a gradual increase in the heat production per square meter of body-surface up to about 12 kg. in weight, with a decrease thereafter. This increase, of course, has special interest for comparison with the rise in the intensity of metabolism in the first part of the curves shown on several of our earlier charts. This increase thus seems to be clearly established, whatever basis of comparison is employed.

It is commonly believed that the calories per square meter are constant for all sizes and weights of individuals. The surface areas here shown are not computed or estimated, but are carefully measured; yet on this chart we find variations in the calories per square meter ranging from 647 calories at a weight slightly under 4 kg. to a maximum of 1,278 calories at a weight of about 12 kg. This great diversity occurs with the lower weights, but even after 12 kg., taking for example a point at approximately 28 to 30 kg., we have ranges from 886 to 1,205 calories.

The sketched curve is not unlike that shown when the calories per square meter are compared with the actually measured surface-area (fig. 40), but it is impossible to consider such a wide scatter of observations as indicating more than a general trend. While, as would be expected, a considerable number of points lie within ±10 per cent, especially at the higher weight values, the large number of points lying outside these wide limits certainly does not justify the effort to stress this relationship as evidence of a physiological law.

The calories per 24-hours per square meter of body-surface referred to weight, as plotted for the girls in figure 43, show such a wide diversity in the distribution of the individual points that only a complicated form of curve, which has obviously not been mathematically determined, will serve to indicate the general trend. Characteristics of this sketched curve are the rapid increase in the values up to 10 kg. in weight, and a tendency for the values to decrease thereafter. Contrary to the results of the observations on boys, there is with girls a clear tendency in the relatively few observations we have to indicate a flattening-out of the curve after 22 kg. Still, extreme caution is necessary in considering any data above 30 kg. as of real significance in indicating the general trend, since we have only three points beyond this weight. The two extremely high values between 36 and 40 kg. are the identical observations which showed abnormally high values on the body-surface chart in figure 39. Further evidence at these weights is absolutely necessary for intelligent discussion. The accumulation of such data is now in progress at the Nutrition Laboratory.

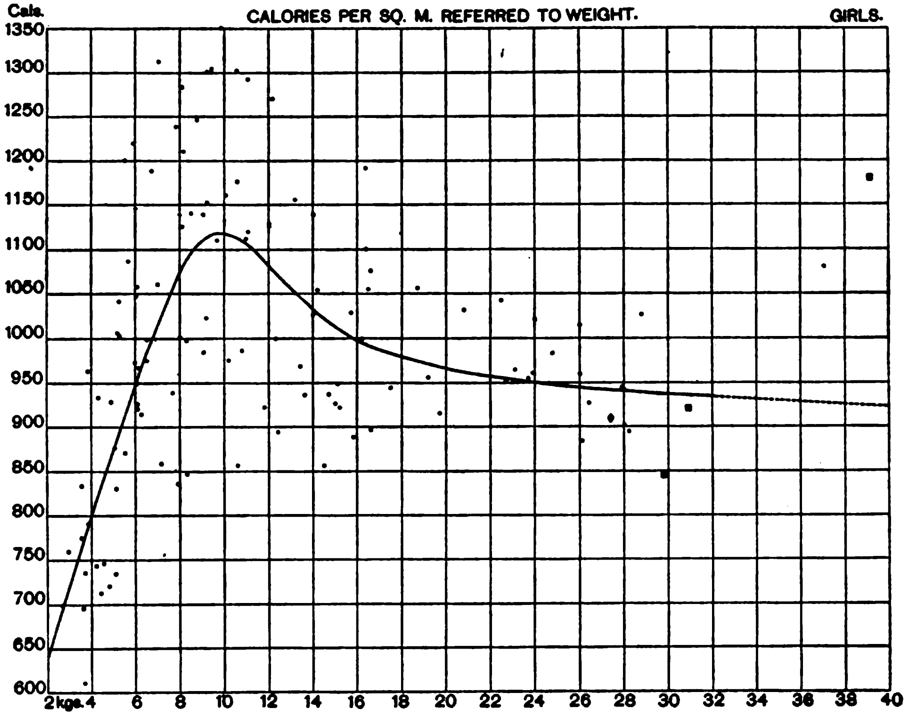

FIG. 43.—Basal heat production of girls per square meter of body-surface per 24 hours referred to body-weight.

Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 39.2 kg. (puberty).

Although the tendency is for the highest metabolism per square meter of body-surface to be noted at about 10 kg., some of the lowest values found in the entire series are also obtained about this time. A large personal element in basal metabolism is therefore apparent, certainly with the younger children. The general form of the curve is somewhat different from that on the same basis shown for the boys, but this is not the place for a special discussion of sexual differentiation.

COMPARISON OF HEAT PRODUCTION PER SQUARE METER (MEASURED), REFERRED TO BODY-WEIGHT, WITH EARLIER DATA (COMPUTED).

As brought out in preceding sections, certain difficulties occur in comparing the results of our study, in which the basal metabolism was directly determined and the surface-area actually measured, with those of earlier investigators, who, aside from Du Bois, were unable to measure the body-surface. Since, however, data were obtained in the earlier investigations for the total metabolism and the body-weight, and occasionally for height and age, we may compute the surface areas for the children studied, probably with considerable exactness.

In computing the body-surfaces of children whose metabolism is given in the earlier literature, we have been guided in large part (1) by the clearly established legality of the Lissauer formula for children up to 10 kg. in weight; (2) by the reasonably satisfactory agreement of the Du Bois height-weight chart down to 20 kg. with body-surfaces actually measured. For the children studied by Murlin and Hoobler, the body-surface was computed by means of the Lissauer surface formula. For the majority of those studied by Magnus-Levy and Falk, the surface areas were derived from the height-weight chart of Du Bois. Since no heights were given for Scharling's children, the two boys of Sondén and Tigerstedt, and a few of Magnus-Levy and Falk's children, the surface areas were computed from the body-weights by means of the formula $K\sqrt[3]{w^2}$ and our new values for the factor K. (See tables 14 and 15, pages 61 and 62.)

The use of these computed surface areas is permissible in computing the calories per square meter of body-surface; but it hardly seems that such a computed area can be used in a comparison of the calories per square meter of body-surface and the body-surface itself, and this has not been attempted. In referring the calories per square meter to weight and to age, the units of measurement for comparison are perfectly definite and hence proper to use.

To avoid any misunderstanding, we call attention again to the fact that for some of the very young children (20 boys and 19 girls) in our own series of observations, the body-surfaces were not measured, but were likewise computed.[1] For these children the Lissauer formula was used, as it was not possible to employ the height-weight chart, since the body-weight was less than 20 kg., which is the lower limit of this chart. As our own results show that the Lissauer formula agrees remarkably well with the measured surfaces for other children weighing less than 10 kg., we feel justified in including these in our tables with the actually measured surfaces.

If we disregard the age of the child measured by Sawyer, Stone, and Du Bois,[2] and consider only weight, it seems quite reasonable to argue that since the Du Bois measurements applied to a child weighing a little over 6 kg. and the Lissauer formula and the linear measurements agree up to 10 kg., we can logically employ the Du Bois linear formula in measuring the body-surface of children weighing somewhat less than 6.3 kg. Du Bois specifically questions the use of the linear formula for body-surface calculations for children under 2 years of age. It would appear, however, that the agreement between the Lissauer formula and the Du Bois surface formula is not a purely accidental one, but represents in all probability a reasonably close physiological relationship. Accordingly, while we must recognize that the Du Bois linear formula may not, according to its authors, be used at present for children under 2 years of age, we have frankly disregarded this and have employed it for these younger children in computing the body-surfaces from the actual measurements. Until it has been disproved that the linear formula does not apply for children so young as this, we believe it is justifiable to use it in this way. If body-surface still continues to attract the attention of physiologists as much as it has in the past decades, a complete verification of the linear formula for children under 2 years of age may naturally be expected inside of a few years.

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[1] See tables 27 and 28, pp. 116 and 120.

[2] Sawyer, Stone, and Du Bois, Arch. Intern. Med., 1916, 17, p. 855.

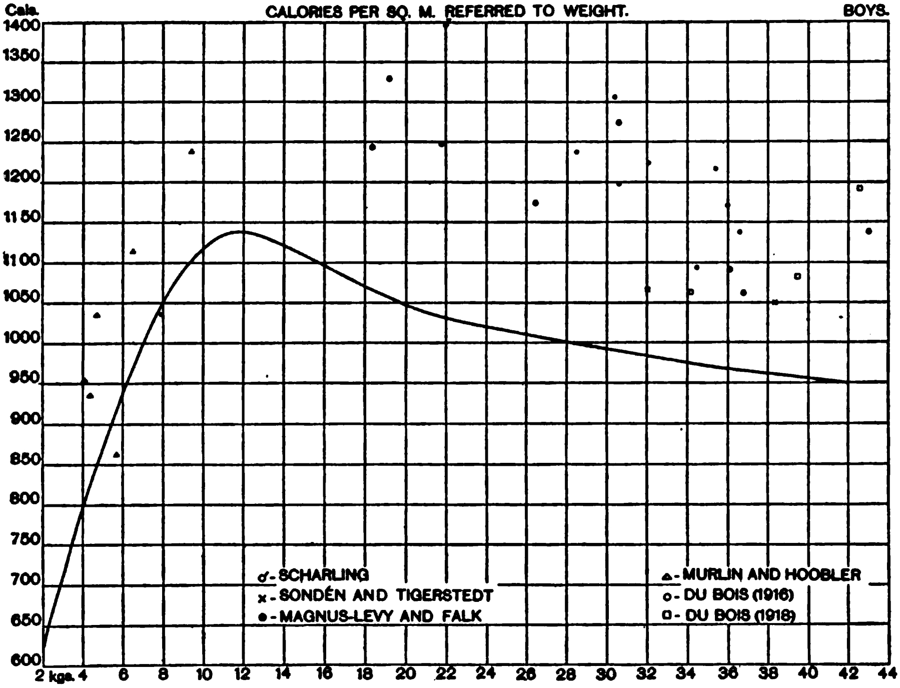

FIG. 44.—Basal heat production of boys per square meter of body-surface per 24 hours referred to body-weight (earlier investigators).

In the comparison of our metabolism data with earlier studies, in which special attention is called to the total calories per square meter per 24 hours referred to body-weight, it is necessary to bear strictly in mind that the surface-areas of the children studied by the earlier investigators were all computed, except those for the Du Bois boy scouts. We have charted the values for boys on the usual scale in figure 44. The sketched curve, which shows the general tendency found in our own results, has also been laid on the chart, although here again it must be emphasized that this curve was drawn with great difficulty and simply shows the general trend in a diagram, with very wide dispersion of the various points.

While comparison with figure 42 shows that few of these points lie outside of the field of our observations, yet we should note that, with the exception of one boy weighing about 6 kg., the points for the children earlier studied lie above our sketched curve. Furthermore, if a smoothed curve were laid through the earlier observations, it would have approximately the same general trend as our own curve, although at a higher level.

While our own data do not warrant the extension of our smoothed curve beyond 42 kg., the data for certain heavier boys should here be recorded. In the 1918 series of Du Bois, the values for four boys, all weighing about 49 kg., are reported and are given in table 30. With all four boys the surfaces were actually measured.

TABLE 30.—*Values outside weight range in figure 44 (Du Bois).*

Kilos.	Cals. per sq. m. per 24 hrs.
49.1	1,054
49.1	1,037
49.3	1,039
48.6	938

TABLE 31.—*Values outside heat range in figure 44 (Magnus-Levy and Falk).*

Method.	Kilos.	Cals. per sq. m. per 24 hrs.
Height-weight chart.....	20.8	1,459
$K\sqrt[3]{w^2}$..................	11.5	1,448
$K\sqrt[3]{w^2}$..................	14.5	1,468

Magnus-Levy and Falk report the heat production of three boys, each with such a high value that it would be necessary to extend our chart beyond permissible limits to include them, although they weighed less than 21 kg. Table 31 shows the data for these three boys.

It is clear that the points for 6 of the 7 boys would lie very considerably above our line if projection beyond the 42-kg. level were permissible. Since we believe that the projection would in all probability fall somewhat lower rather than continue on a level, all of the 7 boys would be above the projected line, although the value for the boy weighing 48.6 kg. studied by Du Bois would fall practically on the line.

With girls the number of earlier observations is extremely few, hardly justifying special chart treatment. The values have been plotted, but are not reproduced here. All of the values are considerably above our smoothed curve. The earlier data for girls are altogether too sparse to warrant even an attempt to lay on a smoothed curve, so no comparisons with our general trend are possible.

Thus, with girls, as with boys, practically all of the earlier work shows a metabolism so much higher than that found by us as to lead us to suspect that strict maintenance of muscular repose was not insisted upon in these earlier observations. Our own results obviously more nearly approach basal, though still not uncomplicated by a possible effect of previously eaten food.

AGE RELATIONS IN THE HEAT PRODUCTION PER SQUARE METER OF BODY-SURFACE.

Thus far the consideration of the heat loss per square meter of body-surface for our subjects has been confined to the two bases, weight and measured body-surface. In view of the small and clearly established age relationship in the metabolism of adults, it is important to note whether age has a special effect upon the metabolism of rapidly growing children. As previously pointed out, the differentiating of the age effect is difficult, owing to the fact that age changes are concurrent with weight, stature, and surface changes. Still, for purposes of special discussion in subsequent chapters, it is advisable to consider the heat per square meter referred to age exactly as we have studied the total calories and the calories per kilogram of body-weight referred to age. This is particularly true when it is recalled that, beginning with the days of Andral and Gavarret, special emphasis has been placed upon the influence upon metabolism of approaching puberty; hence in our curves it is desirable to note the ages of the various individuals and to find the general trend of metabolism at these ages, independent of weight or surface, save as the surface area is partly compensated by computing the heat per square meter exactly as weight has been partly compensated in previous comparisons by computing the heat per kilogram of body-weight.

Figure 45 gives the values for boys for heat per square meter of body-surface referred to age. Recalling that age changes are in the main concurrent with weight and surface changes, it can be seen that the general trend of this curve is somewhat similar to that for the calories per square meter when referred to weight (fig. 42) and when referred to body-surface (fig. 40), exhibiting an increase during the early years up to an age of about 2 years, with a tendency towards a straight-line decrease thereafter. The scatter of individual points makes it difficult to lay on a smoothed curve. We do not defend this use of a straight-line curve and can only take refuge in our oft-repeated statement that the line must be understood to indicate only a trend and may not be referred to with any mathematical exactness.

As in previous charts, one of the boys is marked as showing unmistakable signs of puberty, this point lying above our smoothed curve. Attention will be again called to this fact in subsequent discussion of the influence of the prepubertal stage upon metabolism.

The chief importance of the curve in figure 45 is to show the pronounced metabolism of early youth up to 1 or 2 years. As we have already stated, there can be no great preponderance in the proportion of active protoplasmic tissue in a child 1 or 2 years of age. In all probability we have here a specifically high metabolism at this age, which is certainly worthy of further investigation, with, if possible, a minimizing or elimination of the disturbing factor of stimulus from food (see page 30).

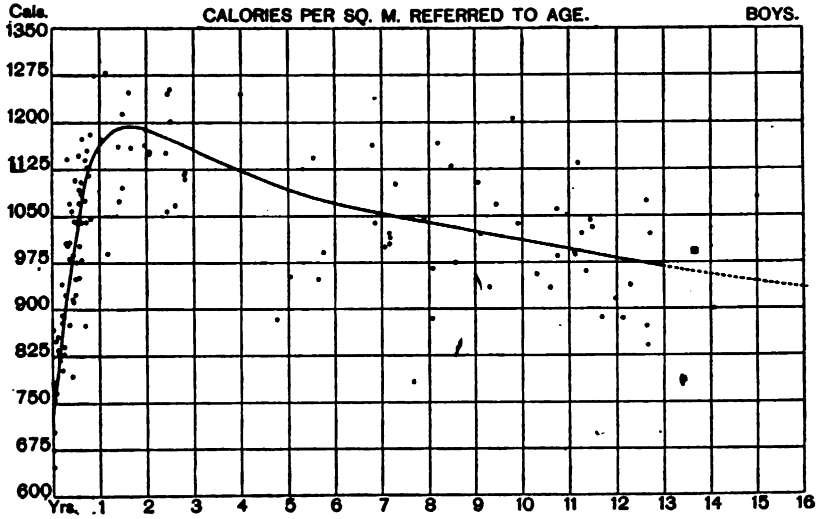

Fig. 45.—Basal heat production of boys per square meter of body-surface per 24 hours referred to age.
Point inclosed in square signifies puberty established.

For the studies on boys made by earlier investigators, a plot is made in figure 46 and our smoothed curve included in the chart. The usual experience is here repeated, namely, that the earlier values, with but one exception, lie above the smoothed curve; in most instances, the points are very much above the line. Especially worthy of note are the high values recorded by Du Bois between the ages of 12 and 14 years. These have brought once more into active discussion the influence of the prepubertal stage upon basal metabolism.

Our observations on girls are all plotted in figure 47, upon which is laid a somewhat complicated smoothed curve, this being the result of an attempt to represent the general trend in spite of the great irregularity and wide dispersion of individual points. The most clearly established feature of the curve is the prevalence of low values at the early ages, rapidly ascending until about 1 or 2 years, with a tendency towards a subsequent decrease. With two of the girls, puberty was definitely established and with one other it was beginning. Of the two former, one point lies below the curve and the other considerably above it. The point for the third girl (12 years and 2 months) lies slightly below the smoothed curve. With one of these girls, measurements were made prior to and subsequent to puberty. At the age of

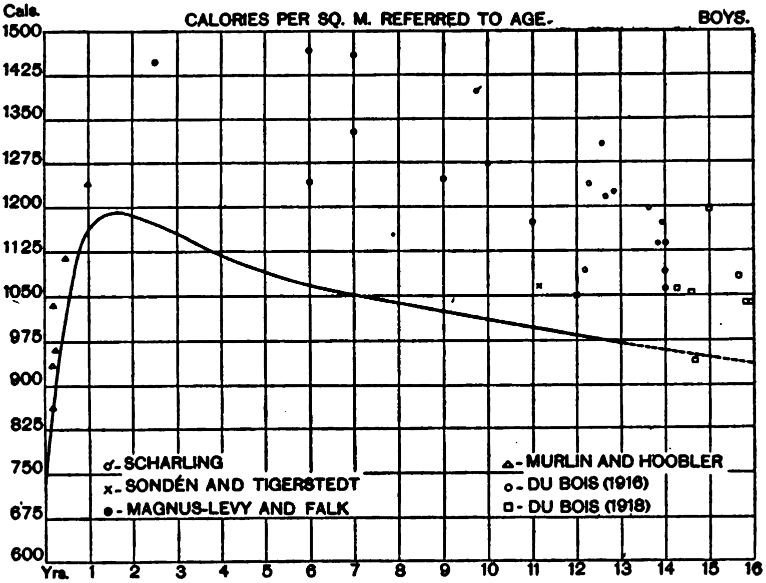

Fig. 46.—Basal heat production of boys per square meter of body-surface per 24 hours referred to age (earlier investigators).

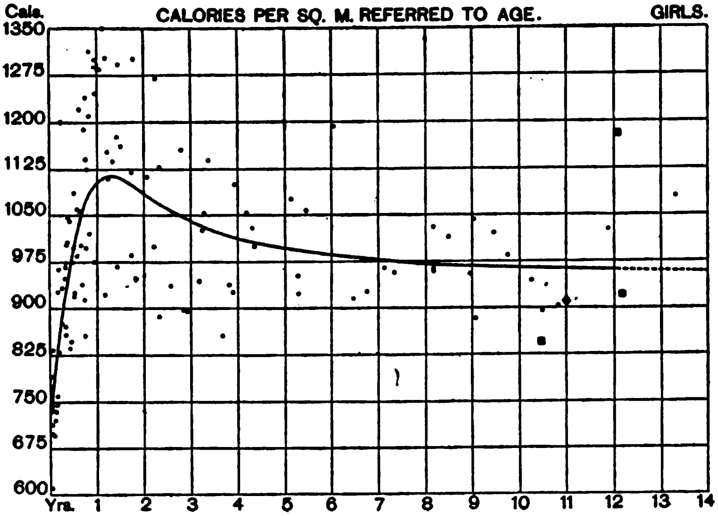

Fig. 47.—Basal heat production of girls per square meter of body-surface per 24 hours referred to age.

Points inclosed in squares signify puberty established. For No. 239 compare point inclosed in diamond (prepubescence) with point inclosed in square at 12 years 1 month (puberty).

11 years, prior to puberty, the heat per square meter was 909 calories. Somewhat over a year later, when the child was 12 years and 1 month old, the heat per square meter had increased to 1,179 calories. This will likewise receive special consideration subsequently.

Bearing in mind that age, weight, and surface area changes are so closely interwoven, it is impossible in any of these age charts to emphasize specifically an age influence *per se*, other than to draw attention to the high point at the age of 1 or 2 years which seems unquestionably to be a specific age influence.

The extremely few girl subjects in the earlier literature make a comparison with our work impracticable. Such few observations as are on record that can be taken as approximating basal (chiefly those of Magnus-Levy and Falk) would all lie considerably above our general smoothed curve. Special chart representation for these scattered observations hardly seems necessary.

INFLUENCE OF SEX AND SEXUAL CHANGE ON METABOLISM.

The wide differences in activity and dietetic habits of boys and girls, commonly observed in every household, early led to a belief in a striking difference between the metabolism of children of the two sexes. Unfortunately, many of the earlier comparisons disregarded body-weight and considered age only. While age-changes with both boys and girls are closely followed by weight-changes, for a strict comparison it is obvious that one may not compare a 12-year-old boy weighing 38 or 40 kg. with a 12-year-old girl weighing 30 kg.

Even the early experiments of Andral and Gavarret[1] are used by the authors as the basis for considerable discussion of the differences between boys and girls. As the authors did not report the body-weights of the children, we can not recompute the data on the better basis of energy per kilogram of body-weight. They conclude that with boys and men there is a steady increase in the carbon-dioxide production from 8 to 30 years, and that between these ages the carbon-dioxide production is greater in amount than that of girls and women of similar ages. Furthermore, they believe that the sexual difference is most pronounced in the adult period (16 to 40 years), the exhalation of carbon dioxide by man during this period being about twice as much as that of woman. The work of Andral and Gavarret is admirably presented by Sondén and Tigerstedt[2] in connection with the discussion of their own researches. As the results of Andral and Gavarret or of Sondén and Tigerstedt may not be looked upon as basal in character, the comparison is probably justifiable, since in all cases the subjects were fairly quiet, although modern conditions for basal measurements were not obtained.

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[1] Andral and Gavarret, Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 129.
[2] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, pp. 54 and 56.

That the question of body-weight was seriously considered by Andral and Gavarret is shown by a portion of their discussion, but they discard this method of comparison as irrational, maintaining that while a woman 25 years old weighs much more than a child 10 to 14 years old, she produces no more carbon dioxide. They further contend that at the menopause the body-weight of women does not necessarily increase, and they have shown that the exhaled carbon dioxide at that time continually increases. It is a matter of regret to modern writers that, although the body-weights of the subjects were known to these investigators, they did not publish them.

Special emphasis was laid by Andral and Gavarret upon the influence of puberty on metabolism. They maintain that with boys the carbon dioxide exhaled increases suddenly to a large amount at the time of puberty, while with girls, on the contrary, the carbon dioxide excretion suddenly ceases to increase at this period and remains nearly stationary until the menopause. It then suddenly increases in a very remarkable manner, and finally, as with man, decreases in proportion to the approach to extreme old age.

Speck[1] studied only three children within the age-range observed by us (a girl of 10 years, a girl of 13 years, and a boy of 13 years), and his conclusions were largely based upon experiments made with older individuals; hence they have little immediate significance in our discussion.

Most of the discussion as to the difference between the sexes in the classic paper of Magnus-Levy and Falk[2] pertains to the ages beyond those of childhood. According to their results, the total metabolism of boys during the years of puberty did not exceed that of adult normal men. With some of the boys the metabolism was less and with some approximately the same as that found with adult men. They mention particularly one boy, accustomed to metabolism experiments, who was studied when he was 16 years old and weighed 57.5 kg., and again 6 years later, when he was 10 kg. heavier. During the period of establishment of puberty the oxygen consumption was 235.6 c. c. per minute and the carbon-dioxide production 192.2 c. c. When puberty had been fully established, the oxygen consumption was 231.3 c. c. and the carbon-dioxide production 200.2 c. c. per minute. In other words, approximately the same values were found at both times. In the later stages of the period of pubertal change, therefore, the total metabolism corresponded to that found after puberty had been fully established. Since there was an increase in weight, the metabolism per kilogram of body-weight obviously decreased, *i. e.*, the oxygen consumption from 4.10 c. c. to 3.43 c. c. per minute per kilogram.

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[1] Speck, Physiologie des menschlichen Athmens, Leipsic, 1892, p. 217.

[2] Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., 1899, Suppbd., p. 314.

Their conclusions are as follows: The gaseous exchange of children per unit of weight is greater than with adults, being larger the younger and lighter the child; this does not apply to the first year of life. Per unit of body-surface (Meeh), the metabolism of children is much greater than that of adults, but during the first year of life it is probably somewhat lower than during later child life.

The metabolism of females is not actually less than that of males; certainly with adults there is no difference. In this respect they do not agree with Sondén and Tigerstedt, who believe that the metabolism of women is less than that of men.

With the younger children the gaseous exchange per kilogram of body-weight for girls is somewhat less than with boys; with larger children the gaseous exchange is about the same with boys and girls. In general, Magnus-Levy and Falk conclude that the metabolism of women in middle life is approximately the same per kilogram of body-weight as that of adult men of the same age and weight; with children and elderly people, the metabolism of females is slightly less than that of males (about 5 to 10 per cent).

Finally, we should refer to the conclusions of Sondén and Tigerstedt,[1] although these were not founded upon basal metabolism measurements. These investigators maintain that in general the carbon-dioxide production of boys, on the basis of both weight and surface, is considerably greater than that of girls of the same age and body-weight, and that the carbon dioxide production of girls, both per kilogram of body-weight and per square meter of body-surface as computed by the Meeh formula, is to the boys as 100 is to 141. This finding, as Sondén and Tigerstedt point out, was earlier suggested by Scharling[2] and Speck,[3] as well as Andral and Gavarret,[4] although the experiments of Scharling and Speck were so few as to make their deductions little more than speculation.

In considering the several charts and diagrams for the measurements made upon our boys and girls, we have occasionally hinted at small but obvious sexual differences in the general form of the curves. Still, from a casual inspection of the individual curves, it would be almost impossible to assert the presence of a pronounced sexual differentiation. For the special purpose of noting sex differences, if they exist, comparison should be made upon the same chart. In figure 48 the total calories are referred to body-weight for both boys and girls, the two curves being taken directly from figures 26 and 27, respectively, and here superimposed. In this comparison of total calories to weight, we find that the absence of a real sexual difference shown with new-born infants[1] persists until about the weight of 11 kg., and that subsequently there is a tendency for the boys to have a somewhat higher metabolism than girls of the same weight, the line for boys being perceptibly above that for girls.

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[1] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 95.

[2] Scharling, Ann. d. Chem. u. Pharm., 1843, 45, p. 214; reprinted in detail in Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 478.

[3] Speck, Physiologie des menschlichen Athmens, Leipsic, 1892.

[4] Andral and Gavarret, Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 129.

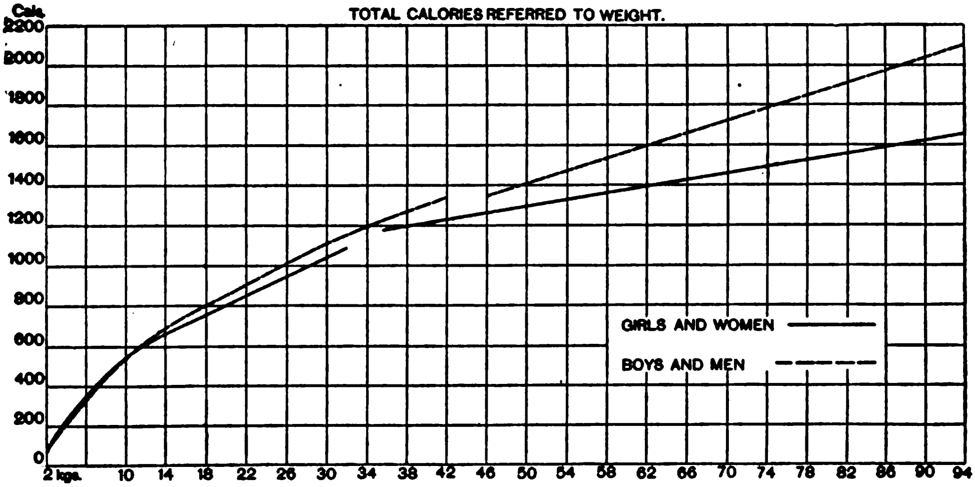

FIG. 48.—Comparison of basal heat production of children and adults per 24 hours referred to body-weight.

Attention should here be called to the fact that in the preliminary presentation of this material,[2] a somewhat different relationship between the curves for boys and girls was noted in that the curve for girls rose above that for boys at the weight of 35 kg. Subsequent revision and elision has justified the caution pronounced at that time to the effect that the number of individuals measured at the higher weights were, with both sexes, too few to justify sweeping conclusions. As here shown in the latest and more complete analysis of our material, we have clear evidence of a sexual differentiation in basal metabolism exhibited above 11 kg., in which the boys show persistently a somewhat higher metabolism than girls of the same weight.

Since a comparison of the metabolism of youth and adults is of general interest, the trends of the metabolism on the basis of total calories referred to weight are also shown in figure 48 for men and women. These curves will be given special discussion later.

A comparison may also be made of the two curves for boys and girls in figures 38 and 39, in which the total heat was referred to actual measurements of the body-surface by the Du Bois method. This comparison has been made in figure 49. As has been pointed out, the general trend of the two curves is alike and the two sexes remain at essentially the same metabolism until the area is 0.48 sq. m. From this point the line for the boys rises above that for the girls, and there is no evidence of a tendency for the two lines to cross later. Figures 48 and 49 thus give clear evidence of a sexual differentiation between boys and girls, with the boys on the whole showing a higher metabolism after the body-weight and body-surface have reached 11 kg. and 0.48 sq. m., respectively.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915; Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 219.

[2] Benedict, Boston Med. and Surg. Journ., 1919, 181, p. 107.

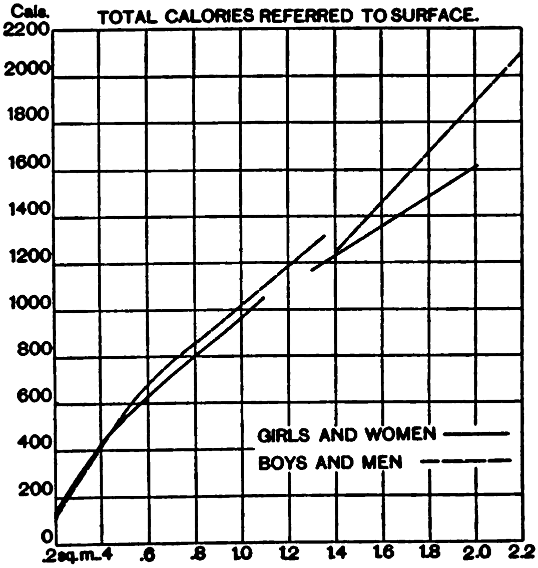

FIG. 49.—Comparison of basal heat production of children and adults per 24 hours referred to body-surface.

The comparison of the total calories to measured surface is, however, a somewhat novel procedure, and physiologists are more accustomed to comparisons of the calories per kilogram of body-weight and the calories per square meter of body-surface referred to weight. Since both these bases of measurement should show a sexual differentiation, if such exist, we have prepared charts giving these comparisons. (See figs. 50 and 51.) The curves for boys and girls in these two charts were taken directly from figures 35, 36, 42, and 43, and are here simply superimposed to bring out the sexual differentiation, which is essentially that noted with the weight curves.

To make an approximate comparison of the heat production per kilogram of body-weight and per square meter of body-surface between youth and adults, we have laid on these charts lines representing grossly the trend of metabolism with women and men with increasing weight, as was done in figure 48 for the total calories referred to weight. It is highly important that these curves should not be interpreted as giving a sharp picture of the actual metabolic changes with increasing weight. Accordingly, since these curves were drawn from plots representing all of our adult measurements, we publish at this point the charts from which these adult curves were derived. (See figs. 52, 53, 54, and 55.) The laying of a smoothed curve on these charts is, owing to the scatter of the points, extremely difficult. While the straight line which is at a constant level in the case of men when the heat per square meter is referred to weight (fig. 54) would seem to be an admission of the constancy of heat production per square meter of body-surface with men, we believe that no one inspecting this chart, with its wide scatter of individual points, can conclude that this line, which represents trend only, can be logically looked upon as a demonstration of the general thesis that the heat production per square meter of body-surface with man is constant. With women it would seem as if a slight slant to the line more closely

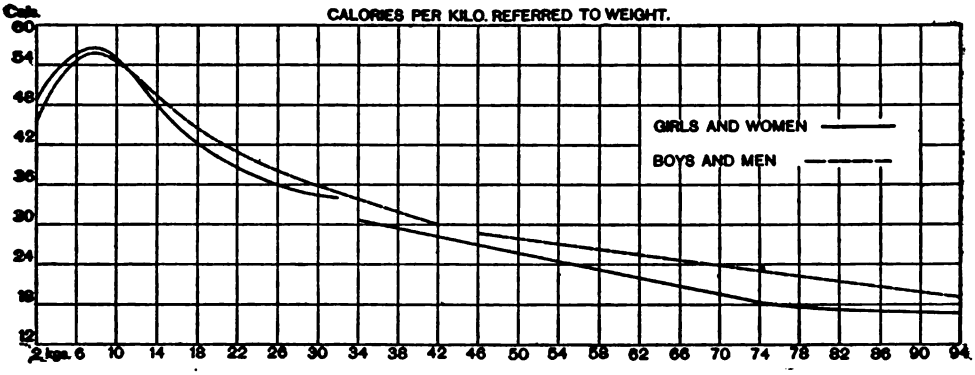

FIG. 50.—Comparison of basal heat production of children and adults per kilogram of body-weight per 24 hours referred to weight.

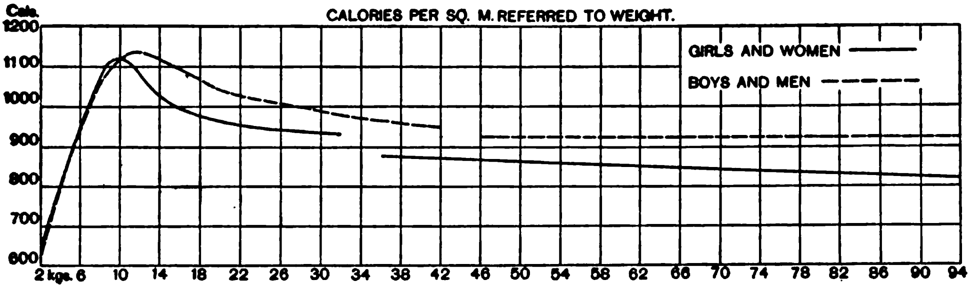

FIG. 51.—Comparison of basal heat production of children and adults per square meter of body-surface per 24 hours referred to weight.

fitted the general trend, but here again, owing to the wide scatter of the points, there is no evidence of regularity in the relationship between heat production and surface area. With youth, even with the wide scatter of the individual points in figures 42 and 43, the lines denoting the general trend show pronounced deviation from a uniformly horizontal level.

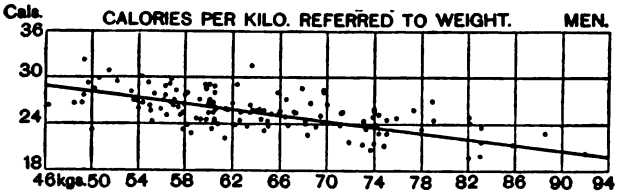

FIG. 52.—Basal heat production of men per kilogram of body-weight per 24 hours referred to weight.

Several important points should be emphasized in connection with the comparisons of the metabolism of youths and adults on all bases of comparison as indicated in figures 48, 50, and 51. One is the quite remarkable coincidence of the extension of the line for boys with that laid down for men, an agreement that is somewhat less striking in the case of the girls and women. The data for the higher-weight boys and lower-weight men, and particularly the higher-weight girls and lower-weight women, are still altogether too few to consider this part of the curves as clearly established. At the moment of writing, further experimental data are being obtained at the Nutrition Laboratory for ages between 12 and 20 years for both sexes. Finally, emphasis must again be laid upon the fact that all of these lines represent at best only general trends, particularly with adults.[1]

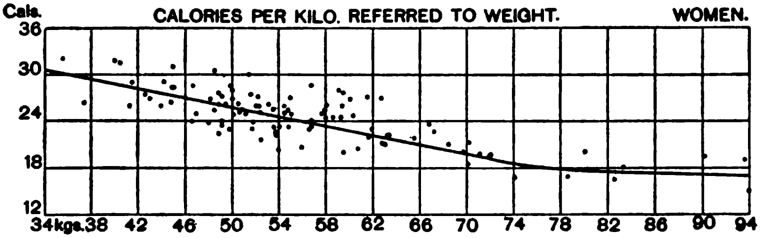

FIG. 53.—Basal heat production of women per kilogram of body-weight per 24 hours referred to weight.

From a consideration of all of the charts in which the metabolism curves for boys and men on the one hand and girls and women on the other are compared, it is evident that the metabolism of boys and men is for practically the entire period of life perceptibly and consistently higher than that for girls and women. While new data on the uncertain period between the weights of 30 and 45 kg. may somewhat modify these general curves, nevertheless it appears clearly established that males have on the whole a higher metabolism than females. When we compare the calories per kilogram referred to weight and the calories per square meter referred to weight, it can be seen that after a weight of about 14 kg. the differences between the two sexes remain almost uniformly constant throughout the entire weight-range.

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[1] See page 132 for description of method of sketching curves.

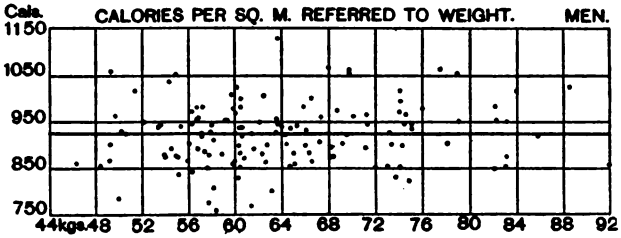

FIG. 54.—Basal heat production of men per square meter of body-surface per 24 hours referred to body-weight.

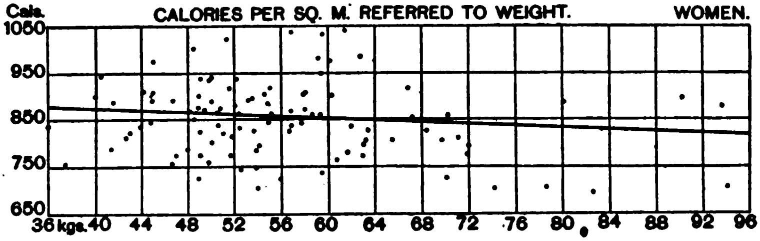

FIG. 55.—Basal heat production of women per square meter of body-surface per 24 hours referred to body-weight.

METABOLISM IN PREPUBESCENCE.

Any discussion of the sexual differences between boys and girls would be incomplete without reference to the important transformation in sexual life taking place at the time of puberty, a transformation that, in the minds of a number of writers, has been clearly apparent in the course of the general total metabolism. Even the early studies of Andral and Gavarret[1] gave this factor serious attention, but unfortunately their data are too meager to be of much value at this time. In 1916 there appeared the first of two remarkable papers by Dr. E. F. Du Bois,[2] of New York, in which the metabolism at the period of development of boys immediately preceding puberty was studied. The importance of the problem under consideration can be no better set forth than by quoting the initial paragraph of this paper.

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[1] Andral and Gavarret, Ann. d. Chim. et d. Phys., 1843, sér. 3, 8, p. 129.
[2] Du Bois, Arch. Intern. Med., 1916, 17, p. 887.

"In the period of development of boys, the years immediately preceding puberty are of especial interest. By this time the figure has lost most of its childish characteristics and the mind has reached a point of great intelligence. Although the individual has scarcely passed the half-way mark in the years of growth, and has only attained half his future weight, yet he resembles the adult much more than he resembles the infant. At this stage the sex glands have not yet begun the rapid development of puberty with its profound effect on the whole organism. Curiously enough there is a sudden increase in the rate of growth which takes place at this time. In fact, we may consider boys in the period of prepubescence as individuals of adult form but of small size, growing rapidly, and as yet scarcely influenced by the internal secretions of the sex glands. The study of their respiratory exchanges may throw light on many problems."

While we unfortunately have to differ with Du Bois as to these experiments meeting the strict requirements for basal metabolism, no paper has called more attention to the possibilities of changes in metabolism in youth as compared to the adult period than has this. We feel that the very high values found by Du Bois must have been due in large part to muscular activity; consequently, a comparison is of interest between his results and those of our observations with boys between 12 and 13 years old, which were obtained under conditions more closely approximating basal.

On reference to figure 22 (page 133), we find records of 6 boys between the ages of 12 and 13 years. Of these, 2 lie above the projected line indicating the general trend of the metabolism, and 4 below. From an examination of this line alone, one can see no increase in the general trend of metabolism peculiar to this age; but since there may be the reasonable objection that our boys were of abnormal weight for their age, we may note the effect of computing the calories per square meter. An examination of figure 45 shows us that of these 6 boys, 2 are again above the line representing the general trend and 4 below, with no indication of a supernormal metabolism.

While the greater part of our observations were made with children in the period of prepubescence, a few observations were made with boys and girls after puberty was established. These are indicated on the several charts by a special designation, *i. e.*, by a square surrounding the point. In figure 22 only one boy is so indicated, the point lying somewhat above the general trend. In figure 45, in which the calories per square meter of body-surface are referred to age, this point likewise lies above the line for the general trend. From this one observation, therefore, one might infer that there was a slight tendency for an increase in metabolism after the onset of puberty rather than prior to it; but obviously no special consideration should be given to a single observation, especially as the determined value is not much above the general trend.

The influence of prepubescence upon the metabolism of girls is likewise of special physiological interest. We note in figure 23, which gives the total calories referred to age, that within the age limits of approximately 10 to 12 years three points are specially designated to show puberty, one very considerably above the general line and two below. With two of these girls, puberty was well established, one at 10½ years and the other at 12 years and 1 month, while with the third child, at 12 years and 2 months, puberty was beginning. It was possible to make observations with one of these girls (No. 239) at 11 years, before puberty began. At the earlier age (specially designated by inclosing the point in a diamond) the metabolism was 984 calories, while 1 year and 1 month later, after puberty was established, it was 1,500 calories. Only in this one case is there apparent evidence of a striking effect of puberty itself upon metabolism. An examination of the rest of the curve shows no indication of a pronounced increase in metabolism during the prepubescent age.

The evidence with this one girl in figure 23 is, however, very deceptive, since on reference to figure 27, in which the total calories are referred to weight, it is seen that in the year and one month intervening between the two observations, this subject had gained in weight practically 12 kg. As a matter of fact, she had also increased 14 cm. in height. Accordingly, comparison may not be made directly on the basis of total calories referred to age without taking into consideration some of the physical factors. With the striking increase in weight, the first obvious correction would be to consider the calories per kilogram of body-weight with this subject at the two ages. This has been done in figure 31, and here we note that the striking differences have practically disappeared, namely: at the age of 11 years, the heat is 36 calories per kilogram of body-weight; at 12 years and 1 month, 38 calories. Precisely the same relationship holds true when we compare calories per kilogram of body-weight at different weights, as shown in figure 36. Consequently, a portion at least of the striking difference in total metabolism noted with this child before and after the establishment of puberty must be ascribed to the pronounced alteration in body-weight.

Having in mind the older conception of the significance of the body-surface area, we should also consider the caloric output per square meter of body-surface with this child. On reference to figure 47, where the values are compared on this basis, we find that after the age of 10 years there is a wide scatter of individual points. The one girl at the age of 10½ years with puberty established shows a value considerably below the general line. Another at 12 years and 2 months, with puberty just beginning, is likewise slightly below the line. The child with values before and after establishment of puberty (No. 239) is represented at the later age, 12 years 1 month, when puberty was fully established, by the highest point on the chart. The heat production per square meter per 24 hours for this girl at 11 years was 909 calories, while at 12 years and 1 month it had risen to 1,179 calories, or an increase of nearly 30 per cent. The general picture is therefore essentially the same as that noted in figure 23 for the total calories referred to age.

When the caloric output per square meter of body-surface is referred to body-weight, as in figure 43, a wide difference in the heat production per square meter at these two weights is exhibited. While, therefore, the great difference in total heat production noted on the chart for total calories referred to age (fig. 23) is in large part removed by reference to heat production per kilogram of body-weight (fig. 31), there still remains a very striking difference between the prepubertal and pubertal stage when the heat production per square meter is considered. Precisely the same order of differences is to be observed with this girl when the total calories are referred to the surface and the calories per square meter are referred to surface in figures 39 and 41, respectively.

What little evidence, if any, can be drawn from these charts for boys and girls as to the influence of prepubescence and the establishment of puberty on metabolism may be summed up in the statement that prior to puberty there is no tendency for a change in the general trend of the basal metabolism. The establishment of puberty in at least one girl resulted in a relatively high metabolism, which was made clear by measurements both prior to and subsequent to the establishment of puberty. Sondén and Tigerstedt[1] and Olin[2] report no increase per kilogram or per square meter following puberty.

Since with our boys and girls we did not find the increase in metabolism which Du Bois found, it becomes necessary for us to disagree with his findings for boys 12 and 13 years old, and we believe our conclusion is justified, that the prepubescent period is without significant effect upon the metabolism of the boy or girl. The evidence regarding the effect of puberty fully established is sufficiently divergent in the existing researches to warrant much further study on this important point. Du Bois's evidence indicates strongly a decrease in metabolism following the prepubescent stage. The very meager evidence we possess indicates a tendency to an increase, although admittedly this is largely based upon the measurements of one girl, which were made before and after the establishment of puberty. Had not the question of the influence of puberty upon the metabolism been raised by earlier investigators, we should not feel that we were in any way justified on the basis of this one experiment in discussing the question. We believe that the chief point to be raised here is that further studies with children of this age are imperative. Such investigation is now in progress at the Nutrition Laboratory.

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[1] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 75.
[2] Olin, Skand. Archiv f. Physiol., 1915, 34, p. 432.

THE PREDICTION OF THE BASAL METABOLISM OF YOUTH.[1]

In the last analysis, one of the most important factors in a metabolism study is the potentiality of drawing from the data a method of predicting the unknown metabolism of a subject. The establishment of a normal, when based upon unvarying laws of either physics or chemistry, results in a standardization of values that makes possible the immediate estimation of the probable resultant of any two or more physical factors. In physiology the normal variation is so great as absolutely to preclude a mathematically established standard without deviations therefrom. On the assumption that the children in this study were normal in the commonly accepted use of that word, we do find, however, that the total metabolism follows a reasonably uniform curve in some of the relationships studied.

While nearly all of our numerous charts show a wide scatter of points, certain charts are characterized by a fairly close grouping of points around the hypothetical line indicating the general trend. These are specially the charts showing the total calories referred to body-weight for both boys and girls (figs. 26 and 27, pages 140 and 142) and the total calories referred to actually measured surfaces for both boys and girls (figs. 38 and 39, pages 161 and 164). From these curves it would appear that it is not impossible to predict with reasonable accuracy the probable basal metabolism of a child when either the weight or the measured body-surface is known. The body-weight is very readily and frequently obtained, but the Du Bois method of measuring the body-surface, while very specific and readily acquired after a little careful consideration of the directions, nevertheless requires such an extensive series of measurements as to make its general use impractical.

In general, the grouping of the individual points about the curves in figures 26, 27, 38, and 39 is often so seemingly compact as to suggest that the curve sufficiently represents the general trend for it to serve as a foundation for the prediction of the basal metabolism of unknown subjects. Still, on closer inspection, the scatter of individual points is noted to be considerable. One deceptive feature of these curves, making an intelligent comparison with curves for adults difficult, is the fact that the deviation from the general line varies greatly as to its percentage value according to the weight of the individual or the size of the surface area; consequently it is only with percentage relationships that one may properly deal.

From an inspection of the curves for calories referred to both surface and weight, it is difficult to estimate with the eye as to which basis, *i. e.*, surface or weight, would give the better method for prediction, although in the earlier consideration of these curves we noted that there seemed to be a somewhat wider dispersion of points about the curves for surface than about the curves for weight. For an exact analysis of, (1) the suitability of these curves for prediction, and (2) of the relative merits of surface and weight curves for prediction, mathematical treatment of each child on the two bases of weight and surface referred to total calories is essential; consequently we have prepared two tables for the boys and girls, respectively, giving the essential physical data for the individual children, and the values for both the measured heat and the heat predicted on the two bases of weight and surface. Since we are testing the accuracy of our general curves for the prediction of heat, the differences between the predicted and actual heat are given in these tables for both methods of prediction on the basis of the predicted less the actual, so that if the prediction is lower than the actual the difference will be indicated by a minus sign. The percentage differences are also given, since percentage values can alone be used for the comparison of children of various sizes.

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[1] A preliminary discussion of this point has recently appeared: Benedict, Proc. Nat. Acad. Sci., 1920, 6, p. 7.

In addition to the data for the predicted heat on the bases of weight and surface, we have employed a third method of prediction for the boys, in which use was made of the multiple prediction formula of Harris and Benedict[1] as proposed by them for the prediction of the most probable total heat production of men. Exactly the same treatment with regard to the differences between predicted and actual, as well as the percentage differences, is accorded this method of prediction. Thus we have in the tables the actual total heat production per 24 hours of each child and then (by the three methods of prediction) the most probable heat production of a child of similar weight or (in the case of surface) of similar surface, taken from the corresponding curve. The differences of the actual from the smoothed curve values are then noted and recorded and the percentage values found. Since with the first two methods of prediction, *i. e.*, those from curves, the smoothed curve is nothing more than an attempt to equalize all the inequalities in the values, theoretically there should be practically the same number of plus and minus differences in the whole series, and in any event the sum of the plus or minus differences should practically equal zero.

PREDICTED HEAT FROM TOTAL CALORIES REFERRED TO WEIGHT (BOYS).

The predicted heat for boys, based upon the curve for total calories referred to weight (see fig. 26) is given in table 32 and may first be considered. A superficial inspection of the table shows an approximately equal distribution of plus and minus signs. While this would tend to indicate that the differences between individuals were in the main eliminated in drawing the curve, special consideration should be given to the numerical and percentage differences of the predicted less the actual heat. The numerical differences are expressed in column *g* of table 32 and vary from 0 to as high as 177 calories. Since there was a very wide variation in the heat actually measured, *i. e.*, from a minimum of 163 calories with two of the youngest boys to as high as 1,401 calories with the oldest boy, the percentage differences alone are of value for comparative purposes. The average percentage difference for the whole series of boys, as given in table 33, indicates that the total heat can be predicted from the curve for calories referred to weight with a deviation of ±7.4 per cent. Although an average error of this magnitude may be considered as large, it must be remembered that the data for growing children are extraordinarily few. Hence, if we are to take advantage of this series of observations, the hint given by the general trend of the line in figure 26 may on the whole be regarded, provided that too much emphasis is not placed upon this method of prediction.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919. In this monograph the differences were computed by deducting the predicted values from the actual, instead of the actual values from the predicted as in the present report.

On inspection of the percentage deviations in table 32, we find that the differences of the predicted from the actual are rather considerable in some instances, there being deviations with 7 boys of 20 per cent or more. In all of these seven instances the weight of the boys is 10.7 kg. or below, suggesting that the error of prediction with small children is much greater than it is with the larger children. Apparently some weight not far from 10 kg. represents an approximate dividing-line between a reasonably close prediction and a much more gross prediction. If we use 10 kg. as an arbitrary dividing-line, and calculate the average deviation of the predicted heat from the measured heat for children weighing 10 kg. and above, we find this average deviation to be ±6.3 per cent. (See table 33.) For the boys under 10 kg., we find the average percentage deviation to be ±8.7 per cent. Thus, what is obvious to the eye, both with regard to the dispersion of points and to the general magnitude of the percentage differences in column *h* of table 32, is amply verified by a calculation of the average percentage deviation of the predicted values from the actually observed values.

That some other weight than 10 kg. may not be slightly better, mathematically, for a division-line is not disproved, but for practical purposes this division seems to be all that the calculations justify. To test the theory that some other weight might be better for division purposes, the percentage differences have been computed for boys weighing 15 kg. and above. On this basis we find that the prediction error is slightly less—that is, it now becomes ±5.8 instead of ±6.3 per cent. Since, however, we purpose predicting the heat, not from a formula, but by drawing points from this curve, the lessening of the

Table 32.—*Comparison of the actual basal metabolism of boys with that predicted: (a) by the curve for "Total calories referred to weight";*[1] *(b) by the curve for "Total calories referred to surface";*[2] *and (c) by the adult masculine normal (multiple prediction) standard.*[3]

Subject No.	(a) Age.	(b) Body-weight (without clothing).	(c) Height.	(d) Body-surface (Du Bois linear formula).	(e) Actual heat per 24 hrs.	Heat per 24 hrs. predicted from curve for "Total calories referred to weight."[1] (f) Predicted.	(g) Predicted less actual (f − e).	(h) Percentage difference [(g×100)/e].	Heat per 24 hrs. predicted from curve for "Total calories referred to surface."[2] (i) Predicted.	(j) Predicted less actual (i − e).	(k) Percentage difference [(j×100)/e].	Heat per 24 hrs. predicted by multiple-prediction (adult masculine) formula.[3] (l) Predicted.	(m) Predicted less actual (l − e).	(n) Percentage difference [(m × 100)/e].
		kilos.	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*		*cals.*	*cals.*		*cals.*	*cals.*	
107	10 days	3.38	51.0	0.23	163	173	+ 10	+ 6.1	163	± 0	± 0.0	368	+205	+125.8
108	11½ days	3.40	50.5	.23	202	174	− 28	−13.9	165	− 37	−18.3	366	+164	+ 81.2
114	1 mo.	3.83	54.0	.25	214	200	− 14	− 6.5	193	− 21	− 9.8	389	+175	+ 81.8
115	1 mo.	3.83	55.0	.24	186	200	+ 14	+ 7.5	180	− 6	− 3.2	394	+208	+111.8
106	8½ days	3.83	53.0	.25	163	200	+ 37	+22.7	193	+ 30	+18.4	384	+221	+135.6
27	8½ days	3.86	53.0	.25	198	202	+ 4	+ 2.0	195	− 3	− 1.5	385	+187	+ 94.4
112	17 days	3.99	....	.26	196	209	+ 13	+ 6.6	205	+ 9	+ 4.6	....	....	....
6	8 days	4.54	52.0	.28	191	242	+ 51	+26.7	240	+ 49	+25.7	389	+198	+103.7
117	1 mo. 3 wks.	4.54	55.0	.27	227	242	+ 15	+ 6.6	225	− 2	− 0.9	403	+176	+ 77.5
61	2 mos.	4.60	56.0	.29	233	246	+ 13	+ 5.6	243	+ 10	+ 4.3	409	+176	+ 75.5
118	1½ mos.	4.71	58.5	.28	232	253	+ 21	+ 9.1	232	± 0	± 0.0	423	+191	+ 82.3
115	2½ mos.	4.71	58.5	.27	255	253	− 2	− 0.8	222	− 33	−12.9	422	+167	+ 65.5
119	1 mo. 1½ wks.	4.96	58.5	.31	268	268	± 0	± 0.0	285	+ 17	+ 6.3	426	+158	+ 59.0
137	4½ mos.	5.04	60.0	.30	324	272	− 52	−16.0	270	− 54	−16.7	434	+110	+ 34.0
124	2½ mos.	5.13	57.0	.31	269	278	+ 9	+ 3.3	274	+ 5	+ 1.9	421	+152	+ 56.5
125	2½ mos.	5.39	58.5	.32	285	293	+ 8	+ 2.8	295	+ 10	+ 3.5	432	+147	+ 51.6
133	3 mos. 2½ wks.	5.81	62.5	.33	329	319	− 10	− 3.0	306	− 23	− 7.0	457	+128	+ 38.9
115	4½ mos.	5.86	63.0	.34	296	322	+ 26	+ 8.8	322	+ 26	+ 8.8	460	+164	+ 55.4
126	2 mos. 3 wks.	5.90	60.5	.33	267	324	+ 57	+21.3	315	+ 48	+17.9	449	+182	+ 68.2
119	4 mos.	6.00	64.5	.33	378	330	− 48	−12.7	312	− 66	−17.5	470	+ 92	+ 24.3

[1] See figure 26, p. 140, and table 36, p. 206.

[2] See figure 38, p. 161.

[3] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 227.

130	3 mos.	6.02	63.0?	.34	305	331	+ 26	+ 8.5	327	+ 22	+ 7.2	462	+157	+ 51.5
118	4 mos.	6.08	65.0	.34	339	335	− 4	− 1.2	322	− 17	− 5.0	473	+134	+ 39.5
132	3½ mos.	6.18	64.0	.34	318	341	+ 23	+ 7.2	331	+ 13	+ 4.1	470	+152	+ 47.8
128	3 mos.	6.32	61.5	.35	296	349	+ 53	+17.9	343	+ 47	+15.9	459	+163	+ 55.1
147	5 mos. 1½ wks.	6.50	63.0	0.37	367	360	− 7	− 1.9	375	+ 8	+ 2.2	468	+101	+ 27.5
155	7 mos.	6.54	68.0	.38	407	362	− 45	−11.1	385	− 22	− 5.4	493	+ 86	+ 21.1
141	5 mos.	6.55	62.0	.36	382	363	− 19	− 5.0	357	− 25	− 6.5	464	+ 82	+ 21.5
148	5 mos. 1 wk.	6.55	66.0	.38	347	363	+ 16	+ 4.6	384	+ 37	+10.7	484	+137	+ 39.5
136	4½ mos.	6.70	67.5	.37	365	372	+ 7	+ 1.9	375	+ 10	+ 2.7	494	+129	+ 35.3
161	7½ mos.	6.70	67.5	.40	429	372	− 57	−13.3	408	− 21	− 4.9	492	+ 63	+ 14.7
115	7 mos. 3 wks.	6.83	65.0	.37	389	380	− 9	− 2.3	376	− 13	− 3.3	481	+ 92	+ 23.7
159	7½ mos.	7.03	66.5	.37	413	392	− 21	− 5.1	376	− 37	− 8.9	492	+ 79	+ 19.1
129	3 mos.	7.07	62.0	.38	311	394	+ 83	+26.7	385	+ 74	+23.8	472	+161	+ 51.8
157	7 mos.	7.11	64.0?	.38	439	396	− 43	− 9.8	387	− 52	−11.8	480	+ 41	+ 9.3
119	6 mos.	7.21	67.5	.39	369	402	+ 33	+ 8.9	399	+ 30	+ 8.1	500	+131	+ 35.5
153	6 mos. 1½ wks.	7.22	67.0	.39	378	402	+ 24	+ 6.3	397	+ 19	+ 5.0	497	+119	+ 31.5
150	6 mos.	7.23	72.0	.39	428	403	− 25	− 5.8	394	− 34	− 7.9	523	+ 95	+ 22.2
156	7 mos.	7.32	65.5	.42	457	408	− 49	−10.7	443	− 14	− 3.1	491	+ 34	+ 7.4
148	7 mos.	7.39	68.0	.39	412	411	− 1	− 0.2	406	− 6	− 1.5	504	+ 92	+ 22.3
158	7 mos.	7.48	66.5	.40	383	416	+ 33	+ 8.6	419	+ 36	+ 9.4	498	+115	+ 30.0
126	6 mos.	7.49	66.5	.40	370	417	+ 47	+12.7	415	+ 45	+12.2	499	+129	+ 34.9
155	10 mos.	7.56	71.5	.41	486	421	− 65	−13.4	432	− 54	−11.1	523	+ 37	+ 7.6
164	8½ mos.	7.58	71.0	.40	455	422	− 33	− 7.3	412	− 43	− 9.5	521	+ 66	+ 14.5
154	6½ mos.	7.91	66.0	.43	452	440	− 12	− 2.7	464	+ 12	+ 2.7	502	+ 50	+ 11.1
138	4½ mos.	7.98	68.0	.41	414	444	+ 30	+ 7.2	431	+ 17	+ 4.1	514	+100	+ 24.2
161	9 mos.	8.09	70.5	.42	473	450	− 23	− 4.9	443	− 30	− 6.3	525	+ 52	+ 11.0
136	6 mos.	8.19	71.0	.43	445	455	+ 10	+ 2.2	454	+ 9	+ 2.0	531	+ 86	+ 19.3
126	7½ mos.	8.24	69.5	.42	413	457	+ 44	+10.7	447	+ 34	+ 8.2	523	+110	+ 26.6
153	8 mos. 3 wks.	8.44	68.5	.44	453	467	+ 14	+ 3.1	466	+ 13	+ 2.9	520	+ 67	+ 14.8
158	11 mos. 3 wks.	8.48	70.5	.45	518	469	− 49	− 9.5	486	− 32	− 6.2	529	+ 11	+ 2.1
119	7 mos. 3½ wks.	8.51	70.5	.43	506	471	− 35	− 6.9	460	− 46	− 9.1	532	+ 26	+ 5.1
148	8½ mos.	8.87	72.0	.44	467	489	+ 22	+ 4.7	466	− 1	− 0.2	544	+ 77	+ 16.5
136	7 mos.	8.93	73.5	.45	454	492	+ 38	+ 8.4	492	+ 38	+ 8.4	553	+ 99	+ 21.8
142	5 mos.	9.14	67.5	.47	372	502	+130	+34.9	517	+145	+39.0	527	+155	+ 41.7
149	5½ mos.	9.33	75.0?	.46	420	512	+ 92	+21.9	498	+ 78	+18.6	567	+147	+ 35.0
170	10 mos.	9.37	74.0	.46	479	514	+ 35	+ 7.3	499	+ 20	+ 4.2	560	+ 81	+ 16.9
138	10 mos. 3½ wks.	9.54	74.5	.45	577	522	− 55	− 9.5	492	− 85	−14.7	564	− 13	− 2.3
158	1 yr. 6 mos.	9.55	77.0	.48	586	523	− 63	−10.8	535	− 51	− 8.7	573	− 13	− 2.2
148	1 yr. ½ mo.	9.71	78.0	.46	537	531	− 6	− 1.1	499	− 38	− 7.1	583	+ 46	+ 8.6
168	9½ mos.	9.94	74.0	.48	531	542	+ 11	+ 2.1	525	− 6	− 1.1	568	+ 37	+ 7.0
158	2 yrs. 1 mo.	10.0	81.0	.51	588	545	− 43	− 7.3	572	− 16	− 2.7	595	+ 7	+ 1.2
161	1 yr. 2 mos.	10.1	77.5	.51	503	550	+ 47	+ 9.3	571	+ 68	+13.5	585	+ 82	+ 16.3

TABLE 32.—*Comparison of the actual basal metabolism of boys with that predicted: (a) by the curve for "Total calories referred to weight";*[1] *(b) by the curve for "Total calories referred to surface";*[2] *and (c) by the adult masculine normal (multiple prediction) standard*[3]—Continued.

Subject No.	(*a*) Age.	(*b*) Body-weight (without clothing).	(*c*) Height.	(*d*) Body-surface (Du-Bois linear formula).	(*e*) Actual heat per 24 hrs.	Heat per 24 hrs. predicted from curve for "Total calories referred to weight."[1]			Heat per 24 hrs. predicted from curve for "Total calories referred to surface."[2]			Heat per 24 hrs. predicted by multiple-prediction (adult masculine) formula.[3]		
						(*f*) Predicted.	(*g*) Predicted less actual (*f* − *e*).	(*h*) Percentage difference [(*g* × 100)/*e*].	(*i*) Predicted.	(*j*) Predicted less actual (*i* − *e*).	(*k*) Percentage difference [(*j* × 100)/*e*].	(*l*) Predicted.	(*m*) Predicted less actual (*l* − *e*).	(*n*) Predicted difference [(*m*×100)/*e*].
		kilos.	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*		*cals.*	*cals.*		*cals.*	*cals.*	
138	1 yr. 4 mos. 3½ wks.	10.1	79.0	0.51	590	550	− 40	− 6.8	570	− 20	− 3.4	591	+ 1	+ 0.2
153	1 yr. 6 mos.	10.2	77.0	.51	553	554	+ 1	+ 0.2	566	+ 13	+ 2.4	582	+ 29	+ 5.2
136	9 mos.	10.6	76.5	.51	588	572	− 16	− 2.7	571	− 17	− 2.9	590	+ 2	+ 0.3
142	8 mos. 1½ wks.	10.7	70.0	.52	456	577	+121	+26.5	586	+130	+28.5	559	+103	+22.6
138	1 yr. 7 mos. 3 wks.	10.9	80.5	.53	656	586	− 70	−10.7	591	− 65	− 9.9	608	− 48	− 7.3
153	2 yrs.	11.2	80.0	.55	657	597	− 60	− 9.1	624	− 33	− 5.0	607	− 50	− 7.6
148	1 yr. 5 mos.	11.3	82.0	.52	559	601	+ 42	+ 7.5	585	+ 26	+ 4.7	623	+ 64	+11.4
158	2 yrs. 6 mos. 1 wk.	11.7	82.0	.54	650	615	− 35	− 5.4	609	− 41	− 6.3	621	− 29	− 4.5
119	1 yr. 1 mo. 3½ wks.	11.8	79.5	.54	684	618	− 66	− 9.6	602	− 82	−12.0	619	− 65	− 9.5
138	1 yr. 11 mos. 3 wks.	11.8	82.0	.57	658	618	− 40	− 6.1	639	− 19	− 2.9	626	− 32	− 4.9
176	2 yrs. 5 mos. 1 wk.	12.3	87.5	.58	720	636	− 84	−11.7	654	− 66	− 9.2	657	− 63	− 8.8
153	2 yrs. 5 mos.	12.5	84.0	.58	667	643	− 24	− 3.6	655	− 12	− 1.8	642	− 25	− 3.7
119	1 yr. 8 mos.	12.5	85.5	.59	687	643	− 44	− 6.4	672	− 15	− 2.2	655	− 32	− 4.7
175	2 yrs. 5 mos. 1 wk.	12.6	82.0	.56	587	646	+ 59	+10.1	626	+ 39	+ 6.6	634	+ 47	+ 8.0
155	2 yrs. 6 mos.	12.7	90.0	.57	711	650	− 61	− 8.6	642	− 69	− 9.7	675	− 36	− 5.1
158	2 yrs. 10 mos.	12.7	84.0	.56	623	650	+ 27	+ 4.3	634	+ 11	+ 1.8	643	+ 20	+ 3.2
155	2 yrs. 10 mos.	13.3	93.5	.60	665	671	+ 6	+ 0.9	674	+ 9	+ 1.4	698	+ 33	+ 5.0
119	2 yrs. 1 mo.	13.6	90.5	.62	717	681	− 36	− 5.0	702	− 15	− 2.1	692	− 25	− 3.5
153	2 yrs. 9 mos. 3 wks.	13.7	87.0	.60	668	685	+ 17	+ 2.5	678	+ 10	+ 1.5	671	+ 3	+ 0.4
177	2 yrs. 7½ mos.	14.6	88.5	.61	649	713	+ 64	+ 9.9	687	+ 38	+ 5.9	692	+ 43	+ 6.6
182	4 yrs.	15.5	94.0	.64	800	740	− 60	− 7.5	719	− 81	−10.1	723	− 77	− 9.6
192	5 yrs. 6 mos. 3 wks.	18.8	106.0	.76	866	825	− 41	− 4.7	816	− 50	− 5.8	818	− 48	−15.5
186	4 yrs. 9 mos. 1 wk.	19.3	110.5	.81	716	839	+123	+17.2	859	+143	+20.0	852	+136	+ 9.0
194	5 yrs. 9 mos. 1 wk.	19.8	107.5	.82	813	854	41	+ 5.0	867	+ 54	+ 6.6	837	+ 24	+ 3.0

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[1] See figure 26, p. 161, and table 36, p. 26.

[2] See figure 38, p. 161.

[3] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 227.

197	6 yrs. 9 mos. 3 wks.	19.9	114.0	0.80	925	857	− 68	− 7.4	846	− 79	− 8.5	865	− 60	− 1.5
204	7 yrs. 2 mos.	19.9	111.5	.82	838	857	+ 19	+ 2.3	867	+ 29	+ 3.5	849	+ 11	+ 3.3
199	6 yrs. 10½ mos.	20.2	115.5	.81	843	865	+ 22	+ 2.6	860	+ 17	+ 2.0	876	+ 33	+ 6.6
187	5 yrs. 3 wks.	20.6	111.0	.83	791	875	+ 84	+10.6	877	+ 86	+10.9	871	+ 80	+10.1
215	8 yrs. 2½ mos.	20.8	116.5	.85	984	880	−104	−10.6	888	− 96	− 9.8	880	−104	−10.6
201	7 yrs. 3½ wks.	21.1	122.5	.87	864	888	+ 24	+ 2.8	905	+ 41	+ 4.7	922	+ 58	+ 6.7
212	8 yrs. 1 mo.	21.1	120.5	.89	785	888	+103	+13.1	925	+140	+17.8	905	+120	+15.3
205	7 yrs. 2 mos. 1 wk.	21.3	117.5	.89	899	893	− 6	− 0.7	924	+ 25	+ 2.8	899	± 0	± 0.0
193	5 yrs. 7 mos. 3½ wks.	23.7	118.0	.90	855	958	+103	+12.0	937	+ 82	+ 9.6	945	+ 90	+10.5
201	7 yrs. 3 mos. 2½ wks.	24.4	124.0	.93	1,021	975	− 46	− 4.5	957	− 64	− 6.3	973	− 48	− 4.7
218	8 yrs. 7 mos.	24.7	128.5	.96	932	983	+ 51	+ 5.5	980	+ 48	+ 5.2	991	+ 59	+ 6.3
222	9 yrs. 3½ wks.	25.0	122.5	.94	1,038	990	− 48	− 4.6	969	− 69	− 6.6	962	− 76	− 7.3
209	7 yrs. 11 mos.	25.1	125.5	1.01	1,057	993	− 64	− 6.1	1,026	− 31	− 2.9	986	− 71	− 6.7
202	7 yrs. 2 mos.	25.2	121.0	.94	944	996	+ 52	+ 5.5	967	+ 23	+ 2.4	970	+ 26	+ 2.8
224	9 yrs. 3 mos. 3½ wks.	25.4	126.0	1.03	959	1,002	+ 43	+ 4.5	1,038	+ 79	+ 8.2	983	+ 24	+ 2.5
223	9 yrs. 1 mo. 2 wks.	25.9	129.0	.99	1,011	1,017	+ 6	+ 0.6	1,008	− 3	− 0.3	1,007	− 4	− 0.4
217	8 yrs. 6 mos.	26.7	123.5	.97	1,097	1,038	− 59	− 5.4	992	−105	− 9.6	994	−103	− 9.4
211	8 yrs. 1 mo. 1 wk.	26.8	129.0	1.07	1,033	1,040	+ 7	+ 0.7	1,076	+ 43	+ 4.2	1,026	− 7	− 0.7
218	9 yrs. 5½ mos.	26.8	133.5	.99	1,054	1,040	− 14	− 1.3	1,005	− 49	− 4.6	1,039	− 15	− 1.4
242	11 yrs. 2 mos. 1½ wks.	26.8	126.0	.99	1,117	1,040	− 77	− 6.9	1,003	−114	−10.2	990	−127	−11.4
232	10 yrs. 4 mos.	28.1	127.0	1.09	1,037	1,072	+ 35	+ 3.4	1,089	+ 52	+ 5.0	1,019	− 18	− 1.7
228	9 yrs. 9 mos. 3 wks.	28.5	126.5	1.00	1,209	1,080	−129	−10.7	1,018	−191	−15.8	1,025	−184	−15.2
244	11 yrs. 4½ mos.	29.5	132.0	1.08	1,039	1,103	+ 64	+ 6.2	1,086	+ 47	+ 4.5	1,056	+ 17	+ 1.6
249	11 yrs. 11 mos. 3 wks.	29.9	135.5	1.19	1,087	1,113	+ 26	+ 2.4	1,174	+ 87	+ 8.0	1,075	− 12	− 1.1
229	9 yrs. 11 mos.	30.1	128.0	1.05	1,092	1,118	+ 26	+ 2.4	1,061	− 31	− 2.8	1,054	− 38	− 3.5
235	10 yrs. 7 mos. 1 wk.	30.3	134.0	1.09	1,015	1,123	+108	+10.6	1,090	+ 75	+ 7.4	1,082	+ 67	+ 6.6
253	12 yrs. 7 mos. 3 wks.	30.4	140.0	1.09	1,163	1,125	− 38	− 3.3	1,087	− 76	− 6.5	1,100	− 63	− 5.4
247	11 yrs. 8 mos. 1 wk.	30.5	141.0	1.16	1,023	1,128	+105	+10.3	1,147	+124	+12.1	1,112	+ 89	+ 8.7
241	11 yrs. 1½ mos.	30.6	136.0	1.10	1,086	1,130	+ 44	+ 4.1	1,100	+ 14	+ 1.3	1,093	+ 7	+ 0.6
236	10 yrs. 8 mos. 3½ wks.	31.0	132.5	1.08	1,147	1,140	− 7	− 0.6	1,086	− 61	− 5.3	1,083	− 64	− 5.6
245	11 yrs. 5½ mos.	31.7	135.5	1.17	1,213	1,154	− 59	− 4.9	1,155	− 58	− 4.8	1,103	−110	− 9.1
256	12 yrs. 8 mos. 2½ wks.	32.8	137.5	1.22	1,246	1,176	− 70	− 5.6	1,202	− 44	− 3.5	1,120	−126	−10.1
237	10 yrs. 9 mos.	33.6	139.5	1.21	1,192	1,192	± 0	± 0.0	1,195	+ 3	0.3	1,154	− 38	− 3.2
240	11 yrs. 1 mo. 1½ wks.	33.8	138.5	1.24	1,230	1,196	− 34	− 2.8	1,220	− 10	− 0.8	1,149	− 81	− 6.6
252	12 yrs. 3 mos. 2 wks.	34.1	139.0	1.25	1,167	1,202	+ 35	+ 3.0	1,221	+ 54	+ 4.6	1,148	− 19	− 1.6
246	11 yrs. 6 mos.	36.9	150.5	1.25	1,283	1,254	− 29	− 2.3	1,221	− 62	− 4.8	1,249	− 34	− 2.7
243	11 yrs. 3 mos. 1½ wks.	37.9	149.5	1.26	1,282	1,273	− 9	− 0.7	1,230	− 52	− 4.1	1,259	− 23	− 1.8
255	12 yrs. 8 mos.	37.9	153.0	1.30	1,096	1,273	+177	+16.1	1,268	+172	+15.7	1,267	+171	+15.6
259	14 yrs. 1 mo.	38.2	151.5	1.34	1,200	1,278	+ 78	+ 6.5	1,295	+ 95	7.9	1,255	+ 55	+14.6
260	15 yrs. 1 wk.	39.0	147.0	1.30	1,401	1,290	−111	− 7.9	1,265	−136	− 9.7	1,237	−164	− 1.7
254	12 yrs. 7 mos. 3 wks.	39.0	151.0	1.33	1,163	1,290	+127	+10.9	1,293	+130	+11.2	1,273	+110	+ 9.5
250	12 yrs. 1 mo. 2½ wks.	41.0	150.5	1.37	1,211	1,325	+114	+ 9.4	1,325	+114	+ 9.4	1,302	+ 91	+ 7.5

percentage deviation simply means that when the body-weight is above 15 kg., the error of prediction is slightly less than when it is between 15 and 10 kg., and considerably less than with boys under 10 kg.

TABLE 33.—*Comparison of the actual basal metabolism of boys with the metabolism predicted (a) from body-weight,*[1] *(b) from body-surface,*[2] *and (c) from the adult masculine normal (multiple prediction) standard.*[3] *(Average values.*[4]*)*

Group.	Basis of prediction.	Number of boys.	Actual heat per 24 hrs.	Predicted heat per 24 hrs.	Predicted less actual.	Deviation of predicted from actual.
			cals.	*cals.*	*cals.*	*p. ct.*
All boys	Weight	128	652	657	±43	±7.4
Below 10 kg.	Do.	60	364	368	±30	±8.7
Above 10 kg.	Do.	68	907	911	±54	±6.3
All boys	Surface	128	652	654	±46	±7.5
Below 0.45 sq. m.	Do.	52	344	342	±25	±7.7
Above 0.45 sq. m.	Do.	76	863	867	±59	±7.3
Above 10 kg.	Multiple prediction standard	68	907	901	±56	±6.3

[1] See figure 26, p. 140, and table 36, p. 206.
[2] See figure 38, p. 161.
[3] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 227.
[4] Averages obtained from data in table 32, pp. 190 to 193.

A comparison of this method of prediction may be made with the results of recent attempts by the Nutrition Laboratory to predict the metabolism of male adults. By means of a multiple-prediction formula derived from the analysis of the basal metabolism of 136 men, a group of 31 college students was tested on this basis and the results compared with the results of actual measurements.[1] The predictions were, on the average, within ±5.3 per cent, a value percepibly better than the ±6.3 per cent noted from the predictions with the boys.[2] This comparison is, however, not quite fair, since these college students were nearly all 20 to 26 years of age, and were unquestionably more homogeneous than a group of children ranging in age from a few months to 15 years. We may still feel, therefore, that on the whole the prediction of the metabolism of children from the curve in figure 26 is not greatly inferior to that for the best existing method of prediction of the values for adults.

PREDICTED HEAT FROM TOTAL CALORIES REFERRED TO SURFACE (BOYS).

In table 32 the values have also been incorporated for the heat predicted from the curve for total calories referred to surface as accurately measured by the Du Bois method. (See fig. 38, page 161.) Giving our attention first to the actual differences as shown in column *j*, we find that they range from 0 to as high as 191 calories; but realizing the very great differences in the actual heat production, we again note that percentage differences alone can be considered for comparative purposes. Exactly the same reasoning with regard to the effect of the curve in smoothing out plus and minus differences in the individual points obtains here, namely, that we would expect to find essentially the same number of plus as minus values, and a superficial inspection of the table bears this out.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 234.

[2] The fact that Harris and Benedict computed these differences by deducting the predicted from the actual heat values does not affect the percentage in this case.

On the basis of weight, 7 instances were noted in which the percentage difference was 20 per cent or more, while the heat based on the surface gives but 5 instances. All but one of these are with children whose body-weight is 10.7 kg. or below. This observation has two important features: First, it confirms the view previously expressed that the error of prediction is largest with the children of small weight. Second, it implies that, so far as extreme errors are concerned, the prediction by surface is somewhat better than the prediction by weight. It is, however, only after a consideration of all the data that one can draw final conclusions. With all the series of boys the average percentage deviation of predicted from the actual is ±7.5 per cent. (See table 33.) Thus it appears that while the number of cases of extreme error was less when the measured surface was used in predicting the total calories, on the average this method of prediction gives slightly greater error than when the calories are referred to weight.

Our general impression that the error of prediction is greater with children with smaller surface is sufficiently substantiated to justify our making a division of the values and considering boys with a surface area below 0.45 square meter in one group and those above this area in another. This division will be not unlike the comparison on the basis of weight, since a body-weight of 10 kg. corresponds approximately to a surface area of 0.45 square meter. The results for this division are also given in table 33 and show that with the boys below 0.45 square meter of surface, the error of prediction is ±7.7 per cent, while the boys above this area have a slightly better percentage, namely, ±7.3 per cent. It thus appears that with the smaller boys the error of prediction is somewhat greater by weight than by surface, *i. e.*, ±8.7 per cent as compared with ±7.7 per cent. This fact, taken alone, would imply a greater correlation between body-surface area and heat production than between body-weight and heat production. On the other hand, with the boys weighing 10 kg. and above and with a surface area of 0.45 square meter and above, we find that the error of prediction is 1 per cent greater when surface area is used—that is, ±7.3 per cent for prediction by surface as compared with ±6.3 per cent by weight. With boys with a body-weight of 10 kg. or above, therefore, more satisfactory results may be obtained in predicting the metabolism from a curve in which the calories are referred to weight than from a curve in which the calories are referred to surface.

If we employ another line of division, as was done in making comparisons on the weight basis, and use a surface area of 0.65 square meter as the dividing-line, we find that the average percentage error for boys with this area or above is somewhat lower, being ±6.8 per cent, as compared with ±7.3 per cent with the division at 0.45 square meter.

It should be borne in mind that the curves used for predicting the metabolism were arbitrarily laid on these charts, and represent simply the resultant personal impressions of five skilled workers with metabolism curves. They are not based upon a mathematical analysis of the points as a whole, and such an analysis has not been attempted. Still, we believe that the curves have a sufficient degree of accuracy to show that there is a definite superiority in the prediction from the curve for calories *versus* weight to that from the curve of calories *versus* surface. It thus becomes of physiological interest to recall that, as a result of metabolism measurements upon adults, it is commonly believed that the relationship between weight and metabolism is by no means so satisfactory as the relationship between surface area and metabolism. The comparison of the predicted and measured heat values for these boys appears to show that the prediction of the metabolism from the weight is not only as good as that from surface, even though we are dealing here with actually measured surfaces, but that it is actually a somewhat better method of prediction for children over 10 kg. Hence these curves and predictions establish the fact that the correlation between weight and basal metabolism is, at least with boys over 10 kg. in weight, of a higher order than the correlation between measured body-surface and metabolism.

In the analysis of the basal metabolism data for 136 men, the average deviation without regard to sign of the predicted from the observed values was in the case of men, when calculated from the *body-weight* by equations, 97.6 calories.[1] Since the average heat production of these men was 1,632 calories,[1] this gives an average percentage deviation of essentially 6 per cent. With boys from 10 to 41 kg., we find from the curve of total calories referred to weight a deviation of ±6.3 per cent. It is of significance that the marvelous changes in muscle, bone, and fat—all changes due to the rapid period of growth through which our study of boys progresses—should not alter appreciably the percentage error of prediction from the general curve so as to make it any greater than that with men. In other words, in spite of the great changes due to growth, the average error is hardly greater for boys than with adults, with whom growth alterations have practically ceased.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, pp. 180 and 182.

COMPARISON OF THE PREDICTED METABOLISM OF BOYS AND MEN.

This discussion thus far has been based upon methods of prediction and, indeed, comparison between youths and adults regarding but one physical factor at a time, *i. e.*, weight or surface. Since with adults it has been shown that weight, stature, and age have each an independent influence on basal metabolism, the comparison of youth with adults will not be complete unless the simultaneous use of these factors is made.

In an earlier report,[1] the metabolism of groups of boys studied by Magnus-Levy and Falk and by Du Bois was compared to the computed metabolism of boys by means of the prediction formula derived from the analysis of 136 men, which took into consideration weight, stature, and age changes. It was found that the values for the actually measured metabolism of these boys was invariably very much higher than those computed by the multiple-prediction formula, which assumed that their metabolism was the same as that of adults of like sex, height, weight, and age. The Du Bois boys, in particular, showed an actual measured metabolism very much greater than that predicted from the formula for men proposed by Harris and Benedict. This was in line with Du Bois's interpretation of his own results on the basis of the heat production per square meter. In view of the calculated results obtained for boys by Harris and Benedict, it seems desirable to compute the metabolism of the boys in our study with the multiple-prediction formula for adults, for while the curves in figures 50 and 51 show a perceptibly higher heat production per kilogram of body-weight and per square meter of body-surface for boys than with men, it will be important to note if the resultant effect of the three varying factors, age, weight, and height, as included in the prediction by the planar equations, is at all in conformity with the trend in metabolism noted with adults. We have, therefore, computed the metabolism of all of these boys, using the multiple-prediction formula for men,[2] *i. e.*, heat equals $66.4730 + 13.7516w + 5.0033s - 6.7550a$. These values have been recorded in table 32, together with the differences between the predicted and actual, both numerical and percentage.

Although special emphasis has been laid in the foregoing discussion upon boys with body-weights of 10 kg. and over, those with smaller body-weights are likewise included. With the very young children, it will be seen that by the multiple-prediction method the error is practically +100 per cent. The metabolism as predicted is found to be too high in every instance until the boy No. 138, with an age of 10 months and 3½ weeks, is studied, when a reversal in sign is found. Subsequently, the predicted metabolism seems to be for the most part not far from that actually measured, showing plus and minus values in about equal numbers.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, pp. 237 and 238.

[2] *Ibid.*, p. 227.

A more careful analysis may be made by comparing the actual heat produced per 24 hours, on an average, for boys weighing 10 kg. and above, with the predicted metabolism calculated from the multiple-prediction formula. These average values are shown in table 33, in which we find that the average predicted metabolism is within ±56 calories, or a percentage deviation of predicted from actual of ±6.3 per cent.

We thus have here a prediction of the metabolism of young boys, based upon the multiple-prediction standard of adults, which shows for the boys weighing 10 kg. or over a remarkable uniformity with that observed from the curve for calories referred to weight. While Harris and Benedict, in putting forth their multiple-prediction methods, specifically stated that its extension to youth under 16 years of age was problematical, it appears that this formula applies to males of all ages of approximately 1 year and over. Considering the rapid changes in weight and stature as compared with the change in age which takes place in this short period from 1 to 13 years, it is an astonishing agreement with the masculine adult prediction standards. Below the age of 1 year it is clear that the formula does not hold true, and the curves of either weight referred to metabolism or of surface referred to metabolism must be relied upon for prediction.

The multiple-prediction equations which involve factors for age, weight, and height do not, however, better the situation, since taking all these factors into consideration gives us a prediction with an error identical with that when the values obtained from the curve in figure 26 for weight alone are considered, *i. e.*, ±6.3 per cent. It should be remembered in this connection that, during this period of growth, the factors of age, weight, and stature are intimately correlated, very much more so than is the case with adults. Adults weighing 70 kg. are much more likely to vary in stature than boys of 30 kg. Similarly, adults weighing 70 kg. may vary in age from early youth to old age, while the variation in age of boys weighing 30 kg. will be very much less. It is thus probable that the body-weights of boys automatically include the variations in age and stature. For practical purposes, therefore, and until the metabolism of children is given biometric analysis, the prediction of the total basal metabolism of boys 10 kg. and above may be made with a reasonable degree of accuracy directly from the curve based upon body-weight.

PREDICTED HEAT FROM TOTAL CALORIES REFERRED TO WEIGHT (GIRLS).

While the charts that have been discussed thus far give little indication of sexual differentiation in the accuracy or ease of prediction of the metabolism of girls as compared with boys, it has seemed desirable to consider the boys and girls separately in regard to the prediction

TABLE 34.—*Comparison of the actual basal metabolism of girls with that predicted: (a) by the curve for "Total calories referred to weight";*[1] *and (b) by the curve for "Total calories referred to surface."*[2]

Subject No.	(a) Age.	(b) Body-weight (without clothing).	(c) Height.	(d) Body-surface (Du Bois linear formula).	(e) Actual heat per 24 hrs.	Heat per 24 hrs. predicted from curve for "Total calories referred to weight."[1]			Heat per 24 hrs. predicted from curve for "Total calories referred to surface."[2]		
						(f) Predicted.	(g) Predicted less actual (f − e).	(h) Percentage difference [(g × 100)/e].	(i) Predicted.	(j) Predicted less actual (i − e).	(k) Percentage difference [(j × 100)/e].
		kilos.	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*		*cals.*	*cals.*	
49	11 days	2.68	48.5	.20	139	124	− 15	−10.8	130	− 9	− 6.5
116	1½ mos.	2.99	.....	.21	163	149	− 14	− 8.6	150	− 13	− 8.0
26	10 days	3.56	50.0	.24	185	189	+ 4	+ 2.2	187	+ 2	+ 1.1
111	13 days	3.57	53.0	.24	200	190	− 10	− 5.0	188	− 12	− 6.0
113	3½ wks.	3.65	53.0	.25	173	196	+ 23	+13.3	201	+ 28	+16.2
110	13 days	3.71	51.0	.25	182	200	+ 18	+ 9.9	198	+ 16	+ 8.8
2	10 days	3.73	53.0	.25	152	201	+ 49	+32.2	200	+ 48	+31.6
123	2 mos. 1 wk.	3.85	53.5	.24	235	210	− 25	−10.6	194	− 41	−17.4
109	12½ days	3.86	51.5	.25	200	210	+ 10	+ 5.0	207	+ 7	+ 3.5
12	9 days	4.20	53.0	.27	199	233	+ 34	+17.1	229	+ 30	+15.1
131	3 mos.	4.34	55.5	.25	235	242	+ 7	+ 3.0	205	− 30	−12.8
35	8 days	4.42	54.0	.28	198	247	+ 49	+24.7	243	+ 45	+22.7
113	1 mo. 3½ wks.	4.55	57.5	.28	207	256	+ 49	+23.7	243	+ 36	+17.4
48	1 mo. 1 wk.	4.81	56.0	.29	211	273	+ 62	+29.4	265	+ 54	+25.6
120	2 mos.	4.90	58.0	.30	274	279	+ 5	+ 1.8	271	− 3	− 1.1
127	2 mos. 3½ wks.	5.03	57.5	.29	255	287	+ 32	+12.5	262	+ 7	+ 2.7
35	1 mo. 1 wk.	5.07	58.5	.30	223	290	+ 67	+30.0	281	+ 58	+26.0
122	2 mos. 1 wk.	5.15	58.5	.31	257	295	+ 38	+14.8	288	+ 31	+12.1
139	4½ mos.	5.19	63.0	.31	315	297	− 18	− 5.7	293	− 22	− 7.0
145	5 mos.	5.25	62.0	.30	317	301	− 16	− 5.0	281	− 36	−11.4
131	4 mos. 1½ wks.	5.27	58.0	.31	311	303	− 8	− 2.6	289	− 22	− 7.1
48	2 mos. 3 wks.	5.54	61.0	.32	388	320	− 68	−17.5	307	− 81	−20.9
113	4 mos.	5.54	63.0	.33	289	320	+ 31	+10.7	320	+ 31	+10.7
151	6 mos.	5.64	60.0	.33	355	327	− 28	− 7.9	313	− 42	−11.8
160	7½ mos.	5.90	62.5	.34	417	344	− 73	−17.5	334	− 83	−19.9
134	4 mos.	5.99	64.0	.34	331	349	+ 18	+ 5.4	331	± 0	± 0.0
140	4 mos. 3 wks.	6.02	60.0	.32	334	351	+ 17	+ 5.1	302	− 32	− 9.6
122	3 mos. 3½ wks.	6.03	62.5	.35	329	352	+ 23	+ 7.0	341	+ 12	+ 3.6
131	7 mos. 2½ wks.	6.08	62.0	.33	353	354	+ 1	+ 0.3	321	− 32	− 9.1
123	6 mos. 1 wk.	6.09	63.0	.34	312	355	+ 43	+13.8	330	+ 18	+ 5.8
139	6 mos. 1 wk.	6.11	65.0	.35	325	356	+ 31	+ 9.5	346	+ 21	+ 6.5
135	4 mos.	6.17	63.0	.35	333	359	+ 26	+ 7.8	341	+ 8	+ 2.4
165	8 mos. 3 wks.	6.24	63.0	.37	338	363	+ 25	+ 7.4	373	+ 35	+10.4
113	5 mos. 3 wks.	6.49	66.5	.36	351	377	+ 26	+ 7.4	359	+ 8	+ 2.3
152	6 mos.	6.52	65.5	.36	357	379	+ 22	+ 6.2	359	+ 2	+ 0.6
123	8 mos. 3 wks.	6.75	65.0	.35	410	391	− 19	− 4.6	338	− 72	−17.6
139	7 mos.	7.00	67.0	.38	406	405	− 1	− 0.2	391	− 15	− 3.7
160	10 mos.	7.05	65.5	.38	492	408	− 84	−17.1	380	−112	−22.8
35	4 mos.	7.17	64.5	.38	329	414	+ 85	+25.8	393	+ 64	+19.5
163	8 mos. 1 wk.	7.63	63.0	.40	375	440	+ 65	+17.3	415	+ 40	+10.7
144	5 mos.	7.91	62.0	.42	353	455	+102	+28.9	441	+ 88	+24.9
166	9 mos. 1 wk.	7.92	68.5	.41	505	456	− 49	− 9.7	424	− 81	−16.0

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[1] See figure 27, p. 142, and table 36, p. 206.

[2] See figure 39, p. 164.

TABLE 34.—*Comparison of the actual basal metabolism of girls with that predicted:* (*a*) *by the curve for "Total calories referred to weight";*[1] *and* (*b*) *by the curve for "Total calories referred to surface"*[2]—Continued.

Subject No.	(*a*) Age.	(*b*) Body-weight (without clothing).	(*c*) Height.	(*d*) Body-surface (Du Bois linear formula).	(*e*) Actual heat per 24 hrs.	Heat per 24 hrs. predicted from curve for "Total calories referred to weight."[1]			Heat per 24 hrs. predicted from curve for "Total calories referred to surface."[2]		
						(*f*) Predicted.	(*g*) Predicted less actual ($f-e$).	(*h*) Percentage difference [($g \times 100$)/e].	(*i*) Predicted.	(*j*) Predicted less actual ($i-e$).	(*k*) Percentage difference [($j \times 100$)/e].
		kilos.	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*		*cals.*	*cals.*	
162	8 mos.	8.00	69.5	0.41	413	460	+ 47	+11.4	429	+ 16	+ 3.9
127	9½ mos.	8.11	67.0	.42	468	464	− 4	− 0.9	433	− 35	− 7.5
160	1 yr. 3½ wks.	8.12	68.5	.41	522	465	− 57	−10.9	423	− 99	−19.0
171	10 mos.	8.18	73.5	.42	502	467	− 35	− 7.0	432	− 70	−13.9
139	9 mos. 1 wk.	8.29	70.0	.42	419	472	+ 53	+12.6	438	+ 19	+ 4.5
146	5 mos. 1 wk.	8.30	68.0	.43	360	472	+112	+31.1	444	+ 84	+23.3
167	9 mos. 1 wk.	8.52	69.0	.46	522	481	− 41	− 7.9	482	− 40	− 7.7
172	11½ mos.	8.80	74.5	.46	568	492	− 76	−13.4	479	− 89	−15.7
146	7 mos.	9.04	71.0	.43	419	502	+ 83	+19.8	445	+ 26	+ 6.2
127	1 yr. 4 mos.	9.06	73.0	.48	549	502	− 47	− 8.6	509	− 40	− 7.3
145	10 mos. 1 wk.	9.19	70.0	.46	474	508	+ 34	+ 7.2	489	+ 15	+ 3.2
166	1 yr. 2½ mos.	9.21	74.5	.49	559	508	− 51	− 9.1	513	− 46	− 8.2
173	11½ mos.	9.22	72.0	.46	600	509	− 91	−15.2	485	−115	−19.2
171	1 yr. 2 mos. 1½ wks.	9.43	76.5	.47	606	517	− 89	−14.7	490	−116	−19.1
139	1 yr. 2 mos. 3 wks.	9.67	76.0	.48	528	527	− 1	− 0.2	502	− 26	− 4.9
172	1 yr. 1 mo. 1½ wks.	9.84	77.0	.51	686	534	−152	−22.2	538	−148	−21.6
122	1 yr. 6 mos.	10.1	78.5	.51	597	544	− 53	− 8.9	544	− 53	− 8.9
145	11 mos. 1 wk.	10.2	72.5	.52	508	548	+ 40	+ 7.9	551	+ 43	+ 8.5
144	9 mos.	10.6	67.5	.52	445	564	+119	+26.7	550	+105	+23.6
173	1 yr. 5 mos.	10.6	78.0	.52	614	564	− 50	− 8.1	552	− 62	−10.1
171	1 yr. 9½ mos.	10.6	85.5	.49	643	564	− 79	−12.3	523	−120	−18.7
139	1 yr. 8½ mos.	10.8	82.0	.54	531	572	+ 41	+ 7.7	568	+ 37	+ 7.0
174	2 yrs. 1 mo.	11.0	79.0	.54	604	580	− 24	− 4.0	573	− 31	− 5.1
172	1 yr. 5½ mos.	11.1	80.0	.55	712	583	−129	−18.1	581	−131	−18.4
166	1 yr. 8 mos. 3½ wks.	11.1	80.0	.53	597	583	− 14	− 2.3	563	− 34	− 5.7
145	1 yr. 2 mos.	11.8	76.0	.56	518	604	+ 86	+16.6	592	+ 74	+14.3
166	2 yrs. 4 mos.	12.0	88.0	.58	655	610	− 45	− 6.9	611	− 44	− 6.7
171	2 yrs. 3 mos. 1 wk.	12.2	89.5	.58	735	616	−119	−16.2	609	−126	−17.1
139	2 yrs. 2½ mos.	12.3	88.0	.59	590	619	+ 29	+ 4.9	620	+ 30	+ 5.1
178	2 yrs. 11 mos.	12.4	92.0	.61	543	622	+ 79	+14.5	637	+ 94	+17.3
166	2 yrs. 9½ mos.	13.2	88.5	.60	692	645	− 47	− 6.8	629	− 63	− 9.1
145	1 yr. 5 mos.	13.4	80.0	.62	600	650	+ 50	+ 8.3	649	+ 49	+ 8.2
139	2 yrs. 6 mos. 3 wks.	13.6	92.5	.65	607	655	+ 48	+ 7.9	673	+ 66	+10.9
139	3 yrs. 2 mos. 3 wks.	14.0	96.0	.64	655	665	+ 10	+ 1.5	664	+ 9	+ 1.4
166	3 yrs. 4½ mos.	14.0	92.5	.60	686	665	− 21	− 3.1	633	− 53	− 7.7
171	3 yrs. 3 mos. 1 wk.	14.2	100.0	.62	657	670	+ 13	+ 2.0	652	− 5	− 0.8
179	3 yrs. 8 mos.	14.5	98.5	.65	560	678	+118	+21.1	679	+119	+21.3
139	3 yrs. 9 mos. 3 wks.	14.7	99.0	.67	624	683	+ 59	+ 9.5	689	+ 65	+10.4
180	3 yrs. 10 mos. 3 wks.	15.0	93.5	.69	640	690	+ 50	+ 7.8	712	+ 72	+11.3
145	1 yr. 9 mos. 3 wks.	15.1	86.5	.67	633	692	+ 59	+ 9.3	691	+ 58	+ 9.2
190	5 yrs. 3½ mos.	15.2	103.5	.69	637	694	+ 57	+ 8.9	712	+ 75	+11.8
183	4 yrs. 3 mos. 3 wks.	15.7	97.5	.65	673	704	+ 31	+ 4.6	679	+ 6	+ 0.9
145	2 yrs. 4 mos.	15.8	94.0	.67	590	706	+116	+19.7	689	+ 99	+16.8
184	4 yrs. 4 mos. 1 wk.	16.2	103.0	.72	715	715	± 0	+ 0.0	733	+ 18	+ 2.5
181	3 yrs. 11 mos.	16.4	98.5	.70	771	720	− 51	− 6.6	721	− 50	− 6.5

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[1] See figure 27, p. 142, and table 36, p. 206.

[2] See figure 39, p. 164.

TABLE 34.—*Comparison of the actual basal metabolism of girls with that predicted: (a) by the curve for "Total calories referred to weight";*[1] *and (b) by the curve for "Total calories referred to surface"*[2]—Continued.

						Heat per 24 hrs. predicted from curve for "Total calories referred to weight."[1]			Heat per 24 hrs. predicted from curve for "Total calories referred to surface."[2]		
Subject No.	(*a*) Age.	(*b*) Body-weight (without clothing).	(*c*) Height.	(*d*) Body-surface (DuBois linear formula).	(*e*) Actual heat per 24 hrs.	(*f*) Predicted.	(*g*) Predicted less actual (*f* − *e*).	(*h*) Percentage difference [(*g* × 100)/*e*].	(*i*) Predicted.	(*j*) Predicted less actual (*i* − *e*).	(*k*) Percentage difference [(*j* × 100)/*e*].
		kilos.	*cm.*	*sq. m.*	*cals.*	*cals.*	*cals.*		*cals.*	*cals.*	
195	6 yrs. 3 wks.	16.4	99.5	0.67	792	720	− 72	− 9.1	689	−103	−13.0
171	4 yrs. 2 mos. 1 wk.	16.5	104.5	.68	718	723	+ 5	+ 0.7	703	− 15	− 2.1
145	2 yrs. 10 mos.	16.6	96.5	.69	618	725	+107	+17.3	710	+ 92	+14.9
188	5 yrs. 1½ mos.	16.6	103.5	.73	782	725	− 57	− 7.3	742	− 40	− 5.1
145	3 yrs. 2 mos.	17.5	98.5	.70	657	748	+ 91	+13.9	716	+ 59	+ 9.0
191	5 yrs. 5½ mos.	18.7	107.5	.75	790	774	− 16	− 2.0	758	− 32	− 4.1
206	7 yrs. 4 mos.	19.2	113.0	.79	752	785	+ 33	+ 4.4	790	+ 38	+ 5.1
196	6 yrs. 5½ mos.	19.7	118.0	.82	747	798	+ 51	+ 6.8	813	+ 66	+ 8.8
206	8 yrs. 2 mos.	20.8	116.0	.84	863	825	− 38	− 4.4	830	− 33	− 3.8
220	9 yrs. ½ mo.	22.5	122.0	.94	977	868	−109	−11.2	910	− 67	− 6.9
189	5 yrs. 3 mos. 1 wk.	22.7	116.0	.87	829	873	+ 44	+ 5.3	858	+ 29	+ 3.5
203	7 yrs. 1 mo. 2 wks.	23.1	119.0	.88	849	882	+ 33	+ 3.9	865	+ 16	+ 1.9
219	8 yrs. 11 mos. 1 wk.	23.7	125.0	.92	880	894	+ 14	+ 1.6	898	+ 18	+ 2.0
210	8 yrs. 2 wks.	23.9	122.5	.93	894	898	+ 4	+ 0.4	904	+ 10	+ 1.1
225	9 yrs. 5 mos. 1 wk.	24.0	120.5	.91	924	900	− 24	− 2.6	885	− 39	− 4.2
227	9 yrs. 9 mos.	24.8	125.5	.94	919	924	+ 5	+ 0.5	908	− 11	− 1.2
214	8 yrs. 2 mos.	26.0	126.0	.97	930	950	+ 20	+ 2.2	936	+ 6	+ 0.6
210	8 yrs. 5 mos. 3 wks.	26.0	123.5	.99	1,002	950	− 52	− 5.2	950	− 52	− 5.2
221	9 yrs. 3½ wks.	26.1	122.0	1.02	902	953	+ 51	+ 5.7	979	+ 77	+ 8.5
198	6 yrs. 9 mos.	26.4	124.5	.99	918	960	+ 42	+ 4.6	953	+ 35	+ 3.8
239	11 yrs.	27.4	133.5	1.08	984	985	+ 1	+ 0.1	1,035	+ 51	+ 5.2
230	10 yrs. 3 mos.	27.9	133.0	1.06	999	998	− 1	− 0.1	1,012	+ 13	+ 1.3
238	10 yrs. 9 mos. 3½ wks.	28.0	135.5	1.05	944	1,000	+ 56	+ 5.9	1,002	+ 58	+ 6.1
234	10 yrs. 5 mos. 3½ wks.	28.2	133.0	1.03	923	1,004	+ 81	+ 8.8	990	+ 67	+ 7.3
248	11 yrs. 10 mos. 3 wks.	28.8	129.0	1.04	1,062	1,016	− 46	− 4.3	992	− 70	− 6.6
233	10 yrs. 5 mos. 2½ wks.	29.8	131.0	1.06	896	1,040	+144	+16.1	1,016	+120	+13.4
251	12 yrs. 2 mos.	30.9	138.5	1.10	1,012	1,068	+ 56	+ 5.5	1,050	+ 38	+ 3.8

[1] See figure 27, p. 142, and table 36, p. 206.

[2] See figure 39, p. 164.

value of the curves for total calories referred to weight and total calories referred to measured surface. The usual scatter of points about these curves is such as to indicate a reasonable regularity and suggest the possibilities of their use for prediction purposes. As we have seen with boys, exact deductions from the curves themselves with regard to the accuracy of prediction are difficult and only a mathematical consideration of the individual differences between the predicted and actual heat of individual subjects can give us a clear conception as to their accuracy. Consequently, a table has been prepared for girls (table 34) in which are given the values for heat as actually measured and as predicted from the curve in figure 27 (total calories referred to weight) and likewise the heat predicted from the curve in figure 39 (total calories referred to surface). For each of these series of values, the differences between the predicted and actual and the percentage differences are given.

Considering first the prediction of metabolism from the curve of total calories referred to weight, we find the plus and minus signs are fairly equal in number, as would be expected from the way the curve was laid on. The magnitude of the differences ranges from 0 to 152 calories, but since the children vary in weight from 2.7 to 30.9 kg., percentage differences alone have value for comparison purposes. In 11 instances the error of prediction is 20 per cent or more; but 10 out of these 11 girls weigh 10.6 kg. or less, thereby confirming the observation made with boys that the error is smaller with the heavier children.

TABLE 35.—*Comparison of the actual basal metabolism of girls with the metabolism predicted: (a) from body-weight,*[1] *and (b) from body-surface.*[2] *(Average values.*[3]*)*

Group.	Basis of prediction.	No. of girls.	Actual heat per 24 hrs.	Predicted heat per 24 hrs.	Predicted less actual.	Deviation of predicted from actual.
			cals.	*cals.*	*cals.*	*p. ct.*
All girls............	Weight	114	545	554	±46	± 9.7
Below 10 kg.........	Do.	58	354	357	±41	±11.8
Above 10 kg........	Do.	56	743	757	±52	± 7.5
All girls............	Surface	114	545	544	±48	± 9.8
Below 0.45 sq. m....	Do.	49	315	312	±36	±11.6
Above 0.45 sq. m....	Do..	65	718	718	±57	± 8.5

[1] See figure 27, p. 142, and table 36, p. 206

[2] See figure 39 p. 164.

[3] Averages obtained from data in table 34, pp. 199 to 201.

The summaries showing the average differences between predicted and actual and the percentage differences for girls are given in table 35. The average error of prediction for all the girls on this basis is there given as ±9.7 per cent. Since we note that the errors are greater with the earlier weights, the girls may be separated into those weighing above or below 10 kg. We find that those below 10 kg. have a deviation of ±11.8 per cent and above 10 kg. ±7.5 per cent, thus furnishing a mathematical demonstration of our conclusion from the inspection of the figures in column *h* of table 34 that the accuracy of the prediction increases with the increase in weight. If a division is made at 15 kg., as was done for the boys, the percentage deviation for the girls with this or a higher body-weight is ±6.1 per cent.

A special reason for separating the girls at 10 kg. is based upon the fact that we found that there was no sexual differentiation in the metabolism of boys and girls up to the weight of 10 kg., so on this basis alone this point seems to be a justifiable place for separation. From a comparison of the figures for the prediction of metabolism from weight for boys in table 33, it will be seen that in every instance the prediction for boys is materially better than that for girls. Thus, with body-weights of less than 10 kg., the error for the boys in the prediction of the metabolism was ±8.7 per cent, and for the girls ±11.8 per cent. Above 10 kg. the metabolism of the boys was predicted with an error of ±6.3 per cent and the girls ±7.5 per cent. For 15 kg. or above, it was ±5.8 per cent for the boys and ±6.1 per cent for the girls. It should be emphasized that these differences are not due to an error in the curve (which is a smoothed curve representing all our measurements), but to the more pronounced physiological differentiation with children of the lower weights. This is particularly the case with children in the first months of life, a considerable number of whom appear on our charts.

PREDICTED HEAT FROM TOTAL CALORIES REFERRED TO SURFACE (GIRLS).

While our analysis of the prediction of the metabolism from the surface for boys gives little reason to expect a better method of prediction for girls with this criterion, it is necessary to analyze carefully the data in table 34 for the heat predicted on this basis.

The actual differences range from 0 to 148 calories, an extremely wide range; but again reference must be made primarily to the percentage differences, indicated in column *k*, for purposes of comparison. With 11 subjects the prediction has an error of 20 per cent or more, but 10 of these are girls with a body-weight of 10.6 kg. or below, corresponding to approximately 0.50 square meter of body-surface. Thus, on the basis of surface as well as weight, the larger children apparently exhibit less errors of prediction by this method of analysis.

When the actual averages are compared (see table 35), we find that the average deviation of the predicted from the actual measurement is ±9.8 per cent, this being the largest general deviation by our methods of prediction, considering the boys as a whole and the girls as a whole. This error in prediction is also slightly higher than that found on the basis of weight and confirms the deduction made from the values for boys, *i. e.*, that the prediction made from surface is on the whole slightly inferior to that from weight.

Realizing that the smaller children, *i. e.*, those with the smaller body-surface, show the greater proportion of large deviations, it remains to be seen whether or not any particular area will give the better prediction. As with boys, a body-surface area of 0.45 square meter, which corresponds to a body-weight of approximately 10 kg., has been selected as the dividing-line. According to table 35, the percentage deviation for the girls with a body-surface area below 0.45 square meter is ±11.6 per cent, while for those above it is ±8.5 per cent, showing a measurably greater error with the smaller children. If, again, we use for the arbitrary dividing-line, the surface area of 0.65 square meter, the percentage deviation for the girls of this surface area or over is ±6.8 per cent, as compared with ±8.5 per cent on the basis of 0.45 square meter.

It is thus seen from the data in table 35 that the error of prediction with girls by surface is slightly better with the smaller children, *i. e.*, those below 10 kg. and below 0.45 square meter, than is the prediction from weight, but with the larger girls the prediction by weight is considerably better than by surface, *i. e.*, ±7.5 per cent against ±8.5 per cent.

It will be noted that in table 34 we have omitted figures regarding the prediction of the metabolism of girls by the adult multiple-prediction formula of Harris and Benedict. The formula for men, which is used to predict the metabolism for boys, is given on page 197 of this report. The formula for women differs considerably from that for men in that the first term is large, being 655.0955.[1] The other terms for weight and stature are both positive, that for age alone being negative. Consequently, since the ages are all small with girls, with a maximum of 15 years, the only negative term would at most correspond to not far from 70 calories. As this formula deals only with those organisms having a heat prediction of not less than 700 or 800 calories, it is obviously impossible to apply the formula to the heat production of young girls. While we might have used the formula for men for this computation and thus studied the relative differences in metabolism between boys and girls, it was believed to be unnecessary, as our several charts point out very clearly the sexual differentiation.

The application of the formula for women to girls is fraught with considerable danger. Throughout the biometrical treatment of the basal metabolism of women and men by Harris and Benedict, it was brought out repeatedly that no method at present available makes it possible to predict the metabolism of women with any approach to the accuracy of the prediction for men. Although in the biometric study referred to approximately 100 women were included, they were by no means so harmonious in physical type as were the men, the correlation of stature and weight being on the whole about half that for men. Unfortunately, the data with which this correlation can be compared are very few, comprising generally the Cambridge students, both male and female, studied by Pearson.[2] With these students a much more homogeneous group was found, since the correlation between weight and height with the female students was considerably better than that found for the male students. With the men included in the Harris and Benedict study, the partial correlation between weight and stature corrected for constant age was for 136 men 0.5772, while for 103 women it was but 0.2995.[1] This alone shows that with the women the correlation between height and weight was considerably lower than with the men, thus indicating greater irregularity in physical configuration and departure from an average.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 227.

[2] Pearson, Proc. Roy. Soc. Lond., 1899, 66, p. 26.

PRACTICAL VALUE OF THE PREDICTION OF BASAL METABOLISM.

Prediction factors are of importance in that it is highly desirable, particularly in clinical work, to have some conception of the general trend of the metabolism of children of a definite age or weight. We believe that we have sufficiently emphasized in all of our charts that the scatter or dispersal of the individual points is so great as to necessitate great caution in considering that any particular normal child may indicate a fixed normal metabolism, to which all other normal children of the same age, sex, height, and weight should conform. This is far from the case.

But if due cognizance is taken of the probable deviations from the general trend, the curves for total calories referred to body-weight and total calories referred to body-surface may be considered as distinctly helpful in indicating whether or not there is great diversity from the general trend with children having any particular configuration or any particular illness, or subsisting upon any dietetic régime or nutritional plane, or with any physiological change affecting the group.

As will be seen, the emphasis in this discussion is laid upon the group. It is clear from the most cursory examination of our several charts that the individual child may vary greatly from the average, and hence it is only with extreme caution that deviation may be interpreted as being of pathological or abnormal nature with any individual child. If special conditions of diet, life, or pathological development are to be studied, it must be clearly established that the special conditions result in the deviation from the general trend in a considerable number of instances or a group. With these cautions in mind, we may suggest that the curves given in figures 26 and 27 may be used directly for predicting the most probable basal metabolism of a quiet, resting boy or girl.

To assist clinicians in rapid estimations of these predictions, we have prepared a table (table 36) giving the most probable heat production for each half kilogram of body-weight for both boys and girls. If the weight of the boy or girl is known, the physician may thus read directly from table 36 the predicted basal metabolism for a child of this weight and compare it with the heat actually measured to note if the measured values are aberrant in any way. Owing to the effort and time required for making the calculations of the body-surface by the Du Bois method, it seems unwise to tabulate the changes in metabolism for each tenth of a square meter. These can always be obtained by direct inspection of the curves in figures 38 and 39 in case surface-area measurements are made.

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[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 59, table 12.

TABLE 36.—*Basal heat production of boys and girls per 24 hours predicted from body-weight.*

Body-weight (without clothing).	Predicted heat.		Body-weight (without clothing).	Predicted heat.		Body-weight (without clothing).	Predicted heat.		Body-weight (without clothing).	Predicted heat.	
	Boys.	Girls.		Boys.	Girls.		Boys.	Girls.		Boys.	Girls.
kilos.	*cals.*	*cals.*	*kilos.*	*cals.*	*cals.*	*kilos.*	*cals.*	*cals.*	*kilos.*	*cals.*	*cals.*
2.5	115	110	11.5	607	595	20.5	873	818	29.5	1,103	1,032
3.0	150	150	12.0	625	610	21.0	885	830	30.0	1,115	1,045
3.5	180	185	12.5	643	625	21.5	898	842	30.5	1,127	1,058
4.0	210	220	13.0	660	640	22.0	910	855	31.0	1,140	1,070
4.5	240	253	13.5	678	652	22.5	925	867	31.5	1,150	1,080
5.0	270	285	14.0	695	665	23.0	940	880	32.0	1,160	1,090
5.5	300	318	14.5	710	678	23.5	953	890	32.5	1,170	......
6.0	330	350	15.0	725	690	24.0	965	900	33.0	1,180	......
6.5	360	377	15.5	740	700	24.5	978	915	33.5	1,190	......
7.0	390	405	16.0	755	710	25.0	990	930	34.0	1,200	......
7.5	418	432	16.5	768	722	25.5	1,005	940	34.5	1,210	......
8.0	445	460	17.0	780	735	26.0	1,020	950	35.0	1,220	......
8.5	470	480	17.5	793	747	26.5	1,033	962	35.5	1,230	......
9.0	495	500	18.0	805	760	27.0	1,045	975	36.0	1,240	......
9.5	520	520	18.5	818	770	27.5	1,058	987	36.5	1,248	......
10.0	545	540	19.0	830	780	28.0	1,070	1,000	37.0	1,255	......
10.5	568	560	19.5	845	793	28.5	1,080	1,010	37.5	1,265	......
11.0	590	580	20.0	860	805	29.0	1,090	1,020	38.0	1,275	......

24-HOUR ENERGY REQUIREMENTS OF GROWING CHILDREN.

With all of these children, the only activity possible was the movement of the arms and legs while the child lay on a bed or cot inside the respiration chamber. There could be no running about and no external muscular work performed. An earlier discussion[1] of the possibilities of an increased metabolism due to the muscular activity of an infant in the lying position has shown that on the average a maximum increase in metabolism of 65 per cent (in exceptional cases of over 200 per cent) may be obtained as a result of vigorous kicking and convulsive crying on the part of a new-born infant.

While our studies were primarily for an investigation of the basal metabolism, and consequently the greatest degree of repose was sought by every possible means, we incidentally secured a considerable amount of data with regard to muscular activity. Certain of the children were restless, so much so that the observations had to be stopped. With very young infants there was at times crying, but with all these conditions the children were lying in bed. Aside from the gross records on the kymograph, to which we have arbitrarily assigned values of I to VI, the statistics of these periods of activity can have little quantitative value to other observers, and accordingly they are not published here. All of the results for these periods have been gathered together, however, and certain deductions seem justified by an inspection of the data. In the first place, the very great increases noted with new-born children may occasionally be obtained with children up to the age of 9 months, but the average of 65 per cent found with new-born babies does not continue after the first few weeks of life. Subsequently, until the age of 6 months, the average increase due to activity may be as high as 40 per cent. As the age of the child increases and voluntary muscular control becomes more possible, the increments noted by us decrease in value, until after 7 years of age an increase due to activity of over 30 per cent of the basal value is rarely found. This obtains for girls as well as for boys.

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[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915, p. 111.

Two important points stand out as a result of this inspection of data: First, that the younger the infant the greater is the percentage increase in metabolism during lying on account of crying and active movement of the body, arms, and legs; and second, that with the older children voluntary control has so increased as greatly to reduce the maximum activity.

These values have special significance in that they throw light upon the practical use of the basal value in the computation of the total 24-hour requirement of the child. From the fact that in our experiments children after 7 years of age rarely had a heat production more than 30 per cent above the basal in periods of restlessness or activity, we feel justified in concluding that the basal value is almost synonymous with the heat production of children over 7 years of age while in bed, save for the stimulating effect of food. Since children are for the most part anywhere from 8 to 12 hours of the day in bed, this forms an important quota of the total 24-hour requirement.

Further than this with the older children we may not go. The great differences in muscular activity of the boy or girl at play, differences which are fully attested by recent studies of the food consumption in boys' schools,[1] shows that the actual caloric output during the waking period and when the children are actively at play is very much greater than the basal output, *i. e.*, that obtained when the child is in bed resting quietly.

With babies, whose time for the most part is spent in bed, somewhat more definite information is at hand, as two 24-hour experiments have been made which have already been reported.[2] With one infant, E. L., 2 months and 3 weeks old, and having a body-weight at the time of observation of 5.03 kg., the basal heat-output per 24 hours was found by computation of results in minimum periods to be 285 calories. The child was 22 hours and 31 minutes inside the respiration chamber. The total heat-output, calculated on the basis of 24 hours, was 372 calories, or an increase of 87 calories (approximately 30 per cent) over basal. The second child, E. S., weighed at the time of the observation 5.76 kg. and was 6 months and 1 week old. She was for 23 hours and 10 minutes inside the respiration chamber, giving a total heat-output per 24 hours of 404 calories. Computation of the basal metabolism by the selection of quiet periods gave 338 calories, the increase over basal being 66 calories or approximately 20 per cent.

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[1] Gephart, Boston Med. and Surg. Journ., 1917, 176, p. 17.

[2] Talbot, Am. Journ. Diseases of Children, 1917, 14, p. 25.

From these two experiments, therefore, it would appear that although it is possible for young children to have percentage increases over the basal for relatively short periods of 60 or 70 per cent, or even more, the total 24-hour heat production on the average may be taken as not far from 25 per cent above the basal. These two isolated points at the ages of 2 months and 3 weeks and of 6 months and 1 week can give only a general hint as to the increase in the 24-hour demand over basal. When children are able to leave the crib or cot and actively exercise by creeping, crawling, and walking around, especially older children when running and playing, the increase above basal becomes very great, and our own observations can obviously contribute in no wise to an estimate of the 24-hour demand on this basis.

The proper estimation of the food needs of growing children can probably never be completely and satisfactorily made from gaseous metabolism experiments. With children, with whom the problem of growth plays so active a rôle, one must supply energy not only for maintenance and for juvenile physical activity, but likewise energy for growth. Even if respiration-chamber experiments were made in which an accurate measurement was made of the entire heat-output for 24 hours of a number of individual children engaging in the usual 24-hour day activity, there still would be the growth factor to be allowed for. In any complex of this nature, one is not justified in saying that, since one of the three factors is difficult of estimation, the others can not be satisfactorily determined. If possible, it is important to determine the basal needs and also the need for extra physical activity.

So far as the basal value is concerned, our experiments, we believe, are reasonably conclusive. So far as the extra needs are concerned, our data supply little if anything of value. The maximum activities noted with children lying in the respiration chamber can, with children over 1½ or 2 years of age, have little meaning. Children below this age are, for the most part, lying either in the bed or crib, and consequently these periods of maximum activity can well correspond to those occurring in the life of an ordinary young infant.

Few of our experiments have included the entire 24 hours, and we cite only two. Accordingly it is necessary for us to consider observations made in other laboratories. In practically all the experiments in which 24-hour periods were possible, few if any were available for comparison with our basal measurements, but they are of prime importance for estimating the probable total 24-hour heat-output for very young children. We have collected from the literature a number of respiration-chamber experiments with children ranging in age from 1½ hours to 9 months. These were practically all carried out with the Pettenkofer-Voit type of apparatus and for the most part were made in Berlin. The data for these experiments are given in table 37, in which is recorded the heat-output of these children computed on the basis of per kilogram per 24 hours. This corresponds very closely, in all probability, to the actual heat production, but does not correspond to the energy needs, since the amount required for growth is not included. Finally, we have recorded the values for the basal heat per kilogram per 24 hours, as predicted from the body-weight curve

TABLE 37.—*Heat production per kilogram per 24 hours of normal boys studied by other investigators.*

Investigator.	Duration of observation.	Age of child.	Body-weight.	Actual heat (computed) per kilo. per 24 hrs.	Heat per kilo. per 24 hrs. predicted from body-weight.[1]	Condition as to activity.
			kilos.	*cals.*	*cals.*	
Birk and Edelstein[2]	12 hrs..	ca. 1½ hrs...	3.1	55	50	Absolutely quiet.[3]
	18.6 hrs.	ca. 1 day...	3.0	55	50	Not stated.
	22.2 hrs.	ca. 2 days..	3.0?	47	50	Do.
Rubner and Heubner[4]............	6 days..	9 wks.	5.2	67	54	Generally quiet.
Niemann[5]........	6 days..	3½ mos. ...	5.1	93	54	Generally quiet; cried some.
Do............	6 days..	5 mos.	5.9	85	55	Quiet.
Do............	6 days..	8 mos.	5.6	[6]89	55	Do.
Do............	17 days..	9 mos.	6.0	[6]91	55	Do.
Hellesen[7].........	3 days..	5½ mos. ...	6.7	68	56	Do.
Do............	3 days..	6 mos.	6.6	74	55	Do.
Rubner and Heubner[8]...........	6 days..	[9]7½ mos. ...	7.6	78	58	Generally very quiet.
Do.[10]..........	3 days..	5½ mos. ...	9.8	68	55	Restless.
Do............	1 day...	5½ mos. ...	9.6	68	55	Do.[3]

[1] See table 36, p. 206.

[2] Birk and Edelstein, Monatsschr. f. Kinderheilk., 1910–11, 9, p. 505.

[3] Without food.

[4] Rubner and Heubner, Zeitschr. f. Biol., 1898, 36, p. 1.

[5] Niemann, Jahrb. f. Kinderheilk., 1911, 74, p. 22.

[6] Child had had light case of grippe and indigestion previously.

[7] Hellesen, Nord. Med. Arkiv, 1915, 48, Nos. 14 and 18.

[8] Rubner and Heubner, Zeitschr. f. Biol., 1899, 38, p. 315.

[9] Girl.

[10] Rubner and Heubner, Zeitschr. f. exp. Pathol. u. Therapie, 1904–05, 1, p. 1.

in figure 26 (see page 140) for weights similar to those noted with the children studied by these investigators.

In practically every instance the measured heat, as computed on the 24-hour basis, is greater than the predicted heat. The one exception is the value found on the third day of the observation of Birk and Edelstein, when the measured heat was 47 calories per kilogram as compared with our prediction of 50 calories. In all the other instances, values very much higher than the predicted heat are found. This would be expected, however, as the predicted heat represents only the basal output, while the measured heat includes for the whole 24 hours not only the basal output, but the heat due to activity when it exists, and particularly that due to the stimulus from food. The predicted heat for the children with body-weights of 3 to 10 kg. ranges from 50 to 58 calories per kilogram of body-weight. Using 55 calories as an approximate average, it can be seen that the measured heat is very considerably higher in most cases, although the values of Birk and Edelstein are only 5 per cent higher, on the average, than the basal. With Niemann's infants, the measured heat is nearly 70 per cent higher in some cases. Even when the protocols indicate that the child is quiet, we find great increases above the basal. It is clear, therefore, that the ordinary 24-hour life of a young child results in a heat production not far from 30 to 40 per cent above basal, a value somewhat in excess of that noted in our two experiments previously cited.[1]

Beyond the weight of 10 kg., or the age of 9 or 10 months, very little has been done aside from the classic research of Sondén and Tigerstedt[2] and that of Rubner.[3] Professor Carl Tigerstedt,[4] in his monograph on the food intake of man, has collected the observations of Hellström, Rubner, von Willebrand, and Sondén and R. Tigerstedt, with boys ranging from 9 to 14 years of age. Although he specifically states that the activity was to a high degree reduced, no claim is made for basal values and the calculated energy output is consequently upon a "moderately quiet" basis. The data thus collected are reproduced here in table 38. From these data, Tigerstedt concludes that the caloric needs, computed on the basis of per kilogram of body-weight, decrease with increasing age. He also finds the same result when the computations are made on the basis of body-surface area, although this is not shown with as great regularity as in the case of weight. As heretofore stated, these observations were made with children on a moderately quiet basis—that is, the children were inside a respiration chamber with the activity considerably restricted.

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[1] Talbot, Am. Journ. Diseases of Children, 1917, 14, p. 25.

[2] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 1.

[3] Rubner, Beiträge zur Ernährung im Knabenalter, Berlin, 1902.

[4] Tigerstedt, Carl, Ueber die Nahrungszufuhr des Menschen in ihrer Abhängigkeit von Alter, Geschlecht und Beruf, Helsingfors, 1915. Also published in Skand. Archiv f. Physiol., 1916, 34, p. 151.

TABLE 38.—*Twenty-four hour energy requirements of boys.*

Age.	Net energy.		Authority.
	Per kg.	Per sq. m.	
yrs.	*cals.*	*cals.*	
9	56	1,325	Tigerstedt, Carl, Ueber die Nahrungszufuhr des Menschen in ihrer Abhängigkeit von Alter, Geschlecht und Beruf, Helsingfors, 1915, p. 78. Also published in Skand. Archiv f. Physiol., 1916, 34, p. 151.
10	49	1,233	
11	50	1,356	
12	48	1,277	
13	37	946	
14	34	862	

Thus far we have been able to consider children at two distinct levels of activity: (1) basal, *i. e.*, with complete muscular repose; (2) with activity restricted by the confines of a respiration chamber. With most children many hours in the day are spent in the school-room. The classic research of Sondén and Tigerstedt has supplied us with information as to the energy requirements of children under these conditions of modern activity; their computations were made by Carl Tigerstedt[1] on the basis of calories per kilogram of body-weight, assuming that 1 gram of carbon dioxide corresponds to 3 calories. Although these values are in no sense basal, they represent data obtained with an approximately uniform muscular activity for the various ages. The results for the age-period within the range of our study are given in table 39, and show clearly a decrease in metabolism per kilogram of body-weight from 7.9 years to 15.5 years of age. The values all lie considerably higher than not only the basal, but also the values for 24-hour chamber experiments given in table 38, thus showing on the whole a somewhat greater degree of activity for the school children. These latter values more nearly approximate the true 24-

TABLE 39.—*Twenty-four hour energy requirements of children (Sondén and Tigerstedt).*

Boys.		Girls.		Authority.
Age.	Heat (computed) per kilo. per 24 hrs.	Age.	Heat (computed) per kilo. per 24 hrs.	
yrs.	*cals.*	*yrs.*	*cals.*	
7.9	70	7.9	70	Tigerstedt, Carl, Ueber die Nahrungszufuhr des Menschen in ihrer Abhängigkeit von Alter, Geschlecht und Beruf, Helsingfors, 1915, p. 79. See also Skand. Arch. f. Physiol., 1916, 34, p. 151.
9.6	75	9.9	53	
10.5	69	11.2	52	
11.4	66	12.2	46	
12.5	62	13.2	43	
13.8	62	14.0	41	
14.5	60	15.1	35	
15.5	50	15.6	40	

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[1] Tigerstedt, Carl, *loc. cit.*

hour requirement than those previously discussed, although even here the children were not studied during their outdoor or extra-chamber activity.

In this connection a study may be made of the curves in figures 33 and 34 (page 152), in which comparisons are made between the basal metabolism values of our observations and the values obtained in the chamber experiments of foreign investigators just discussed. The curves representing our values for boys from 7 to 16 years and for girls from 7 to 14 years are obviously projected for the sake of comparison, as material for the later ages is lacking. The other two curves on the boys' chart correspond to the values computed by Carl Tigerstedt from the earlier chamber experiments (table 38) and the extensive series of observations by Sondén and Tigerstedt on school children ranging in age from 8 to 23 years. On the assumption that the school children would have a varying degree of activity which would be measured with a fair degree of accuracy by the carbon-dioxide production per 2 hours, we selected for the plotting of the Sondén and Tigerstedt curve the more probable minimum carbon-dioxide values at each age, discarding those that were obviously increased by activity. (See table 4, page 10.) Even with this method of eliminating the excessively high carbon-dioxide production, it can be seen that the heat-output obtained with school children was very much higher than either the values found in the 24-hour chamber experiments included in table 38 or (more especially) the basal values obtained by us. Of special significance are the two experiments of Sondén and Tigerstedt with two sleeping boys, one 11 and the other 12 years of age. Their results, indicated by small crosses, lie very near our basal values.

As an approximate figure, one may state that the caloric output of school children in the school-room would be, with boys, approximately 75 per cent above basal (see figure 33); with girls the increment would be more nearly 50 per cent (see figure 34). Although not sufficiently accurate for use in computing the entire 24-hour needs of growing children hese figures are of distinct value in interpreting the food needs of young children and the sum total of the day's activities of a growing child. It is a tribute to the foresight and skill of the Scandinavian investigators to realize that now, after more than 25 years, these experiments still remain of definite practical value.

To sum up, we have in these two measurements, *i. e.*, the basal value and the value for school children, two steps in the important computation of the 24-hour requirement. The basal requirement is substantially the energy requirement during sojourn in bed, this period with children varying from 8 to 10 or even 12 hours. The school value will represent the requirement for 5 to 6 hours of the day. It is thus possible to compute the total energy output for 16 to 18 out of the 24 hours, though in the remaining 6 hours the child may be occupied in such vigorous muscular exercise as to require a very large correction of these figures before the ultimate 24-hour computation may even be approximated.

To explain the extraordinary needs of growing children solely upon the basis of activity is somewhat difficult. The activities are, it is true, enormous. The food consumption is proportionately great. The deposition of tissue must be provided for from the food intake, and this, in turn, augmented above the true needs for simple physical activity. In all probability a factor by no means to be neglected is the stimulus to metabolism resulting from the ingestion of food. As has been shown in the report of an earlier research[1] on mixed diets, especially when large amounts of food are taken, approximately 6 per cent of the total caloric intake is eliminated as extra heat, which has been technically termed the "cost of digestion."

The final computation of the total 24-hour food-needs or heat-output of a growing active child will require considerable research. The heat-output of children at play is entirely a matter of speculation. The determination of such heat production is by no means a technical impossibility; indeed, the large respiration chamber at the Nutrition Laboratory is designedly constructed for the measurement of exactly this type of group activities, and it is hoped that information on these points may ultimately be secured. In any event, it is clear that the caloric needs of growing children are very much greater than they are commonly supposed to be. The lesson to be drawn from our observations on private-school children (see page 72) is that outdoor life and physical activity contribute towards the development of a larger individual, so far as height, *i. e.*, skeletal growth, is concerned, with likewise a greater weight with children of the same age. But it is probable that even these children, with superior surroundings and presumably better medical examination, care, and dietetic supply, may advantageously be supplied with larger amounts of food than they at present take. One could infer, therefore, from these observations, that, aside from the possibilities of digestive derangements, it would be impossible to supply the growing child with an excessive amount of food. Every effort may legitimately be expended to secure a maximum skeletal growth and the development of children above so-called average weight. We believe that our investigation shows clearly that the average weight for children is distinctly below the ideal or physiologically desirable weight.

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[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 341.